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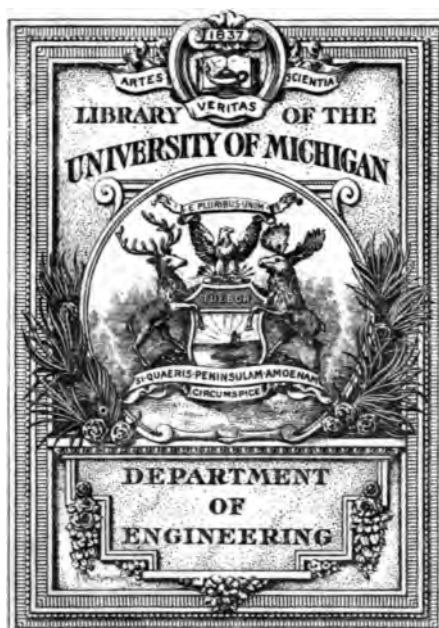
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THE GAS MOTOR

BY
MAX KUSHLAN

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THE GAS MOTOR

BY



MAX KUSHLAN, B. S., Assoc. M. W. S. E.

**Author of Practical Talks for the Modern Steam
Engineer, Practical Physics, Etc.**

CHICAGO

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CONTENTS:

Introduction.

Part I—General Principles.

Chapter I. Elementary Theory of Internal Combustion Engines:—Heat as a form of Energy. Heat Units. The Mechanical Equivalent. Heat Values of Fuels. Explosive Mixtures of Gas with Air. Temperature and Pressure Requirements. The Gas Engine Cycle. The Indicator Diagram. Effect of varying Gas Mixtures. Effect of varying Gas Supply. Effect of advancing and retarding the spark. Regulation of Gas Engines. Rating. Efficiency. Questions on Chapter I. Page 1.

Chapter II. The Gas Supply:—Vaporization of Solid and Liquid Fuels. Physical Properties of Gasoline. Tests. Gravity Supply System. Advantages. Disadvantages. Pressure Supply System. Pressure Gage. The Function of the Carbureter. Floating Valve. Spraying Nozzle. The Needle Valve. Mixing Chamber. Air Supply. Throttle Valve. Common Types of Carbureters. Gas Supply Troubles. Remedies. Questions on Chapter II. Answers to Questions on Chapter I. Page 25.

Chapter III. Elements of the Single Cylinder Engine:—The Four-Stroke Single-Acting Engine. The Two-Stroke Single Acting Engine. The Double Acting Engine. The Cylinder. Ports. Valves. Piston. Connecting Rod. Wrist Pin. Crank Case. Crank Shaft. Piston Rod. Cross-head. Engine Bearings. Keys. Fly Wheel. Muffler. Compression Leaks. Causes. Tests. Remedies. Questions on Chapter III. Answers to Questions Chapter II. Page 52.

Chapter IV. The Multiple Cylinder Engine:—Arrangement of Cylinders. Valve Mechanism. Cam Shaft. Two Cylinder Horizontal Engine. Two Cylinder Vertical Engine. Four Cylinder Vertical Engine. Six and Eight Cylinder Engines. Advantages of Multiple Cylinders. Limitations. Cylinder Troubles. Remedies. Questions on Chapter IV. Answers to Questions on Chapter III. Page 81.

Chapter V. The Ignition System:—Requirements of the Ignition Spark. Magnetic Effect of an Electric Current. Principle of Electro-Magnetic Induction. Ignition Circuit of a Single Cylinder Engine. Dry Cells. Storage Cells. The Induction Coil. The Condenser. The Primary Circuit. The Secondary Circuit. Spark Plug. Ignition Circuit for a Multiple Cylinder Engine. The Commutator. Low Tension Magneto. High Tension Magneto. The Magnetic Switch. Measuring Instruments. Ignition Troubles. Remedies. Questions on Chapter V. Answers to Questions on Chapter IV Page 106.

Chapter VI. The Lubricating System:—General Qualities of Lubricants. Cylinder Oils. Grease. Graphite. Sight Feed Oiling System. The Splash Feed System. Forced Feed System. Oil Strainers. Non-Return Forced-Feed System. Oil Cups. Multiple Lubricators. Grease Cups. Lubrication Troubles. Remedies. Questions on Chapter VI. Answers to Questions on Chapter V Page 152.

Chapter VII. The Cooling System:—General Principles of Heat Radiation. Air Cooling System on Motor-Cycle Engines. Water Jackets. Water Circulating Systems. Circulating Pumps. Radiators. Fans. Non-Freezing Mixtures. Piping. Troubles Due to Improper Cooling of Cylinders. Remedies. Questions on Chapter VII. Answers to Questions on Chapter VI. Page 168.

PART 2—Practical Applications.

Chapter VIII. The Stationary Gas Motor:—Gas Producers. Natural Gas. Illuminating Gas. Blast Furnace Gas. Oils and Distillates. Rating of Stationary Engines. Thermal Efficiencies. Arrangement of Cylinders. Governor. Lay Shaft. Cooling System. Scavenging. The International Harvester Engine. Fairbanks-Morse Vertical Engines. The Nash Engine. Elyria Stationary Horizontal Engines. St. Mary's Tandem Engines. Duplex Gas Engines. Fuel Injection. Care of Stationary Gas Motors. Questions on Chapter VIII. Answers to Questions on Chapter VII. Page 189.

Chapter IX. Automobile Motor Transmission:

—Mechanism of Gearing. Spur Gears. Bevel Gears. Worm Gears. Planetary Gears. Differential Gears. Slide Gear Transmission. Differential Gear Transmission. Range of Speeds. The Bevel Clutch. The Internal Expansion Clutch. The Multiple Disc Clutch. Care of Transmission System. Questions on Chapter IX. Answers to Questions on Chapter VIII. Page 231.

Chapter X. Automobile Motor Operation:—

Starting the Engine. Electrical Self-Starter. Ignition Control. Gas Control. Speed Control. Screw and Nut Steering System. Rack and Pinion Steering System. The Mechanism of Steering Knuckles. The Ball and Socket Connecting Link. Internal Expansion Brakes. External Expansion Brakes. Countershaft Brake. Brake Lining. Operating Troubles. Remedies. Questions on Chapter X. Answers to Questions on Chapter IX. Page 260.

Chapter XI. Motor Requirements For Aviation:—Fundamental Principles of Aviation. Power Requirements For Aviation. Differences in design of Automobile and Aeroplane Motors. Question of Weight. Ratio of Stroke to Diameter, Number and Arrangement of Cylinders. Crank-Shaft Connections. Question of Continuity of Service. Cooling System. Lubrication. Special Heating Coils. Speed Regulation. The Effect of the Propeller. Motor Rating. Efficiency. Questions on Chapter XI. Answers to Questions on Chapter X. Page 278

Chapter XII. Types of Aviation Motors:—Conventional Four-Cylinder Engine. Horizontal Opposed Type. V-Type Motors. The Wright Motor. The Curtiss Motor. Fan-Type Motors. Star Type Motors. Two-Cycle Motors. Rotary Types. X-Form Motors. Gnome Revolving Cylinder Motors. The Sunbeam Aviation Motor. The Liberty Motor. Weights of Standard Aeroplane Motors. Present Limitations. Future Possibilities. Questions on Chapter XII. Answers to Questions on Chapters XI and XII Page 306.

Appendix:—

- I. Useful Constants and Formulae.
- II. HP. Rating of Gas Motors.
- III. Glossary of Technical Terms.

Index:—

ILLUSTRATIONS

Fig.		Page
1.	The four-stroke cycle.....	13
2.	Indicator diagram of Ideal engine with unequal strokes	16
3.	Indicator diagram of Ideal engine with equal strokes	17
4.	Indicator diagram of typical gas engine.....	19
5.	The hydrometer.....	29
6.	Pressure supply system.....	35
7.	Float-feed carbureter of the Schebler-Wheeler type	37
8.	Multiple spray float-feed carbureter.....	41
9.	Automatic carbureter with spring-valve feed.....	43
10.	The four-stroke single-acting engine.....	55
11.	The two-stroke three-port engine.....	61
12.	The two-cycle two-port engine.....	63
13.	Horizontal single-cylinder engine.....	65
14.	Section through cylinder of horizontal four-cycle motor	66
15.	Construction of inlet valve and cage used on single-cylinder throttling engine.....	69
16.	Parts of a piston.....	70
17.	Marine type of connecting rod.....	71
18.	Horizontal two-cylinder motor with tandem cylinders	83
19.	Horizontal duplex motor.....	84
20.	Four-cylinder horizontal opposed type motor.....	85
21.	Four-cylinder vertical motor.....	87
22.	Four-cycle V-type motor.....	88
23.	Three-cycle fan-type motor	89
24.	Five-cylinder star-type or radial motor.....	90
25.	Two-cylinder horizontal opposed engine.....	92
26.	Four-cylinder vertical engine.....	95
27.	The magnetic field.....	111
28.	Lines of force.....	112
29.	A solenoid.....	113
30.	Connections of the make-and-break system for the single-cylinder engine.....	117
31.	Common type of igniter.....	119
32.	Burnley dry cell.....	121

Fig.	Page
33. Cells in series.....	123
34. Cells in parallel.....	123
35. Series-parallel connection.....	123
36. Modern type of a storage battery.....	126
37. Complete element with insulators.....	134
38. Portable cells sealed.....	134
39. Wiring diagram of jump-spark system for single-cylinder engine.....	136
40. Spark plugs.....	139
41. Wiring diagram of the jump-spark system for a four-cylinder engine.....	140
42. Sight-feed oil cup.....	159
43. Multiple lubricators for forced-feed system.....	160
44. The multiple forced-feed lubricating system.....	162
45. Mechanically circulated water cooling system.....	173
46. Plunger-type water pump.....	174
47. Rotary gear pump.....	176
48. Centrifugal pump.....	177
49. Radiators.....	179
50. Cooling fan.....	180
51. Gas producer.....	192
52. Horizontal oil engine.....	207
53. Section through vertical engine.....	209
54. Type of a vertical engine.....	211
55. Longitudinal section through horizontal tandem engine.....	212
56. Cross section of horizontal tandem engine.....	214
57. Longitudinal section of tandem engine.....	216
58. Cross section of tandem engine.....	217
59. Longitudinal section of horizontal duplex engine....	219
60. Cross section of four-cylinder vertical 1000 HP. Diesel motor.....	221
61. Longitudinal section of 1000 HP. Diesel motor.....	223
62. Automobile power transmission system.....	234
63. Spur gear.....	235
64. Bevel gears.....	238
65. Worm gears.....	240
66. Planetary gears.....	242
67. Three-speed slide gears.....	246
68. Four-speed slide gears and differential bevel gears...	248
69. Bevel clutch.....	252
70. Internal expansion clutch.....	253
71. Multiple disc clutch.....	254
72. The steering system.....	265
73. Rack and pinion steering system.....	267
74. The steering knuckle.....	268
75. Automobile brake with "Raybestos" lining.....	270

Fig.		Page
76.	Air pressure on inclined plane.....	280
77.	Forces acting on aeroplane to its velocity.....	282
78.	Vivinus four-cylinder aviation motor.....	308
79.	Longitudinal view six-cylinder Benz motor.....	319
80.	Cross-section six-cylinder Benz motor.....	312
81.	Call horizontal opposed four-cylinder aviation motor	314
82.	Cross-section Mercedes-Renault 12-cylinder motor..	316
83.	Sixteen-cylinder V-type Antoinette motor.....	317
84.	Farcot fan-type six-cylinder aviation motor.....	319
85.	Gobron-Brille X-type eight-cylinder aviation motor.	324
86.	Gnome revolving-cylinder aviation motor.....	326

TABLES

No.		Page
1.	Properties of gas engine fuels.....	10
2.	Properties of petroleum products.....	30
	Table of four-cylinder action.....	98
3.	Sulphuric acids. Mixture with water by weights....	129
4.	Friction loss in pounds per square inch in the discharge of water through pipes.....	184
5.	Values of lifts and drifts at various angles of an aeroplane having a velocity of 50 m. per hour....	284
6.	Power required for propelling an aeroplane at various velocities with an angle of inclination of five degrees	287
7.	Data on standard aviation motors.....	333
8.	HP. rating of gas motors.....	344

APPENDICES

No.		Page
I.	Useful constants and formulae.....	342
II.	HP. rating of motors.....	345
III.	Glossary of technical terms.....	346
	Index	351

INTRODUCTION

The recent development in the field of gas-driven motors has been so unusually rapid, covering such a great variety of forms and practical applications, that it seems at present to hold the most prominent place in the attention of engineers and inventors, as well as of the non-technical public. It is hardly necessary to enumerate the various engineering improvements that were brought about by the perfection of the modern gas engine. It is sufficient to point out that the automobile, the motor-boat and the aeroplane, were made possible in their present form of almost general successful use due to the development of the modern gas motor.

The steam engine has a distinct field of application for the heavier power-consuming devices such as power plants, hoisting engines, railroad trains, etc., due to the low cost of fuel in certain localities, and its capacity for large and continuous output of energy. But for small and intermittent power the gas engine has a decided advantage,

since the fuel is applied here directly to the working medium without the loss of heat through the intervening air and metal, and without the need of a separate furnace and boiler, thus avoiding all the preliminary losses in power before the working fluid reaches the engine. Where an independent source of power is required, as is the case with motor-driven vehicles, the gas motor seems, for the present at least, to be the only source of power that has met with practical success. Its superiority lies in the fact that it needs less attention, it requires less space, it can develop its power very quickly, and it operates at a higher rate of efficiency.

The present limitations in the working efficiency of the gas engine are due primarily to the mechanical difficulty in varying the length of each stroke of the cycle in order to bring it closer to the ideal conditions for complete expansion; also, to the inability of the cylinder metal to retain its mechanical strength at the higher temperatures required for a perfect cycle. There are many other losses in the present gas motor due to imperfect methods of mixing and regulating the gas to insure complete combustion; also, to the difficulty of obtaining the proper temperature and pressure at the instant the gas is exploded, and to the wasteful effects of back-pressure during exhaust. These,

and many other minor features have been considerably improved in the numerous recent designs, and these are changing at such a rapid rate of progress that what seems standard practice at present will probably be out of date in a few years from now.

On account of this rapid stride in development of the gas motor, it was found inadvisable to dwell in this book too closely upon the minute details of the great number of engines and their accessories now on the market, as such books are numerous, and their usefulness is of a temporary nature, since the detailed information given in them soon becomes obsolete and misleading. Such familiarity with actual details could best be acquired first-hand, by practical experience in operating and repairing these motors.

On the other hand, to treat the subject from a theoretical point of view would limit the use of this book to a few highly trained specialists, who have ready access to the many excellent technical books dealing with the theory of gas engines.

The author has therefore attempted to make this a practical book, by adhering to the fundamental principles rather than to details; by avoiding the use of any technical terms without clearly defining their meaning; and, finally, by illustrating these general principles with concrete examples

of the most recent applications of the gas engine to stationary power plants, motor-vehicles and aeroplanes.

It is hoped that with such a treatment of the subject, this book will perform a useful service to the beginner as well as to the experienced operating engineer by making the study and operation of the gas motor both interesting and profitable.

The questions given after each chapter will be found of considerable help in reviewing the subject-matter and for purposes of instruction. The correct answers to these questions will be found at the end of each succeeding chapter, and it is suggested that these should be used as a check of the student's work.

MAX KUSHLAN.

CHICAGO, ILL
JANUARY, 1918

CHAPTER I.

**ELEMENTARY THEORY
OF
INTERNAL COMBUSTION ENGINES.**

The term "Internal-Combustion Engine" applies to all types of prime movers in which heat is transformed into mechanical work by burning the fuel directly in the working cylinder, to distinguish them from engines receiving their energy in the form of pressure generated outside of the cylinder. To the first category belong all types of gas and oil engines. To the second class belong the steam engine and the air engine in which the heated air is kept separated from the fuel.

In order to clearly understand the action of the internal combustion engines in generating their heat and transforming it into mechanical power, we must first learn the fundamental principles underlying the generation and utilization of heat as a working medium.

HEAT AS A FORM OF ENERGY.

All the known forms of energy, such as mechanical work, electric power, chemical activity, etc., can readily be transformed into heat. In fact,

whenever any of these forms of work are used for practical purposes in any process, the so-called "wasted" energy usually appears in the form of heat. By the term "wasted" energy we mean that portion of the work that is used up for purposes which are not of any practical value to the particular process on hand, and are therefore considered as losses.

Thus, when a moving object meets with frictional resistance there is a certain amount of heat generated in the moving body and in the resisting material; when two bodies strike one another with any appreciable velocity the force of their impact is partly absorbed by a definite amount of heat.

The change from electric power to heat takes place mostly by the heating of the conducting material through which an electric current is passing, caused by the resistance of the conductor to the flow of current.

One of the most common methods of generating heat, which is of special interest to gas engineers, is the release of heat energy stored in various substances by means of chemical combination, such as the action of an acid upon a metal, or the burning of fuel, which is really a rapid chemical combination of the hydrogen and carbon contained in the fuel with the oxygen of the air.

In all the above cases we find that the various forms of energy are easily changed into heat; but

the reverse process does not take place so easily, i. e., it is much harder to convert the heat back into mechanical, electrical, or chemical energy.

The transformation of heat into mechanical work is accomplished by **expansion** of the particles of the working medium to which heat is supplied. In case the working medium is a solid or a liquid substance, the expansion caused by heat is relatively small on account of the strong adhesive force between the particles of these substances. In case heat is added to a gas it will expand very rapidly; and if this gas be confined to a closed vessel restricting its expansion, the gas will exert a **pressure** upon the walls of the vessel proportional to the amount of heat supplied to the gas. This is the general theory of the action of steam or gas upon the piston of an engine used to convert heat into mechanical power.

HEAT UNITS.

There are no instruments in existence for measuring the **quantity** of heat directly. But the intensity of heat, or its **temperature**, is readily measured by means of instruments called **thermometers**. The temperature of a substance does not serve as a measure of its energy, but is merely an indication of the condition of its heat in the same manner as the height of a column of water does not measure the quantity of water, but indicates the unit pressure upon its supporting surface.

The two principal types of instruments used at present for measuring temperatures, are the Fahrenheit and the Centigrade thermometers.

In the Fahrenheit thermometer the range in temperature between freezing and boiling of water is equally divided into 180 degrees, the freezing point is marked 32, and the boiling point is located at 212 degrees. A temperature of 50° F. (50 degrees Fahrenheit) means that it is 50 degrees warmer than zero, or 18 degrees above freezing, on the Fahrenheit scale.

In the Centigrade thermometer the range between freezing and boiling is divided into 100 degrees, the point of freezing being marked 0, and the boiling point 100°, so that a temperature of 50° C. (50 degrees centigrade) indicates that it is 50 degrees warmer than freezing on the centigrade scale.

Since every Fahrenheit degree is equal in length to $\frac{100}{180}$ or $\frac{5}{9}$ of a Centigrade degree, a given number of Fahrenheit degrees above 32 multiplied by $\frac{5}{9}$ will give us the corresponding number of Centigrade degrees. This rule can be expressed by the formula:

$$(F-32) \times \frac{5}{9} = C, \text{ and } C \times \frac{9}{5} + 32 = F.,$$

where F and C represent the number of degrees of Fahrenheit and Centigrade respectively.

The quantity of heat supplied to any material in raising its temperature depends upon the following three factors:

- (1) Its **weight**, measured in pounds.
- (2) The natural capacity of the substance for absorbing heat, known as its **specific heat**, measured in heat-units.
- (3) The **temperature** gained by the addition of heat, measured in degrees.

Water is usually taken as the standard substance with which all others are to be compared. Its specific heat is therefore considered equal to 1.0, and the amount of heat required to raise one pound of water one degree Fahrenheit is taken as the standard unit of heat, called the **British Thermal Unit**, usually written B. T. U.

Using the French, or Metric system of measures, the standard unit of heat is the **calorie**, which is the amount of heat required to raise one kilogram of water one degree centigrade.

The amount of heat required to raise any substance to a higher temperature is equal to the product $W \times S \times T$, where W is its weight, S is its specific heat, and T the number of degrees raised due to the addition of the heat.

THE MECHANICAL EQUIVALENT OF HEAT.

The conversion of heat into mechanical power, and vice versa, of mechanical energy into heat, has a definite relation. The mechanical work performed by a physical body depends upon two factors:

(1) The **force** which the body has to overcome in performing the work, measured in **pounds**.

(2) The **distance** through which the body moves in opposition to such a force, measured in **feet**.

The amount of work done in resisting the force of one pound through a distance of one foot is the standard unit of mechanical energy, and is termed one **foot-pound**, usually written **Ft.-Lb.** In raising 10 lbs. five feet from the ground we perform 50 ft.-lbs. of work.

The **mechanical equivalent** of heat is the number of foot-pounds of mechanical energy which is required to generate one unit of heat. From numerous experiments it was found that one B. T. U. is equivalent to 778 ft.-lbs., which means, that assuming no losses, it will take 778 ft.-lbs. of work to heat up one pound of water one degree F., and that one B. T. U. will generate sufficient power in an ideal engine to perform 778 ft.-lbs. of work.

HEAT VALUES OF FUELS.

The heat value of a fuel is the amount of heat generated by a definite weight of this fuel when it is burned under the most favorable conditions. The process of burning or **combustion** consists in combining chemically the carbon and hydrogen contained in all fuels with a sufficient quantity of oxygen contained in the air. In general, the combination of any elementary substance with oxygen is termed oxidation; and the rate with which this combination takes place determines the nature of the process, and the quantity of heat that is available for useful work, before it escapes to the surrounding objects.

The most rapid rate of oxidation, taking place almost instantaneously, is called an **explosion**, which is the most efficient method of generating heat from a fuel, since the heat created at the highest available temperature of that fuel has no time to escape and is almost entirely available for useful work. All internal-combustion engines operate on this principle.

In order to obtain from any fuel the greatest possible amount of its heat, which is known as its heating or **calorific value**, we must fulfill the following three conditions:

- (1) The supply of oxygen must be sufficient for a **complete combustion**, so that none of the elements of the fuel are wasted.
- (2) In the case of a gas, the fuel must be

under **pressure**, in order to bring the particles closer, so as to reduce the space in which the explosion takes place to a minimum.

(3) A very small portion of the fuel must be raised to a **temperature** high enough to start the combustion at a rapid rate, after which it will quickly spread through the rest of the fuel.

The heating values of common fuels are determined experimentally by means of an apparatus called a **calorimeter** in which a definite quantity of the fuel is supplied with a proper amount of oxygen, which mixture is tightly closed in a metallic vessel, after which it is exploded by means of an electric spark. The heat generated is accurately measured by immersing the vessel in a definite quantity of water of known temperature and noting the rise in temperature of the water due to this heat. In this manner were determined the calorific values of the fuels given below in Table I. (Properties of Gas Engine Fuels.)

EXPLOSIVE MIXTURES OF GAS WITH AIR.

The quantity of air necessary for the complete combustion of a given fuel depends upon the heating qualities of the fuel, as well as upon the pressure and temperature at which combustion takes place.

In the first place, since the atmospheric air is made up of one part of oxygen and about 3.8 parts of nitrogen, by volume, it will take about 4.8 times

as much air to burn a certain fuel as the theoretical quantity of oxygen required for combination with the carbon and hydrogen contained in it.

To determine the proper mixture, by volume, for the efficient explosion of air with a certain gas, we must therefore know the exact chemical analysis of that gas and the proportion of the volume of oxygen taken by each constituent element of the gas. Then the total volume of oxygen required for all the elements of a unit volume of the fuel will give us the proper proportion of oxygen needed. This value should be increased about 4.8 times to determine the **theoretical** proportion of air and gas for a perfect explosion. A fuel containing a greater number of the so-called **hydro-carbons**, or substances made up of hydrogen and carbon, will have greater calorific values, since those elements by their oxidation generate the heat of combustion. Such substances are termed **rich fuels**, and these will evidently require more air for their combustion than the **lean fuels** having lower heating values.

By examining the Table of Fuels (Table No. 1) we find that such is actually the case.

The theoretical proportions of air required for explosive mixtures with the various fuels, are usually increased in actual practice. This is due to the fact that our present methods of mixing are imperfect and, in order to prevent wasting the fuel, we must provide a greater quantity of air so

PROPERTIES OF GAS ENGINE FUELS

NAME OF FUEL	Density in Lbs.	Heating Value in B.T.U.†	Ignition Temp. in Degrees F.	Cu. Ft. of Air Required for Combustion		Compression in Lbs. per Sq. In.	Pressure of Explosion Lbs. per Sq. In.	Temp.† of Explosion Degrees F.
				Theoretical	Actual			
Natural Gas....	.0459 per cu. ft.	1000 per cu. ft.	1100	9.00 per cu. ft.	12.60 per cu. ft.	130	375	3000
Natural Gas.....		1000	1000	.....	.....	110	245	.....
Producer Gas (Anthracite)..	.065	140	1450	1.20	1.85	160	360	.....
Producer Gas (Bituminous)..	.....	160	1350	2.20	3.20	.....	.....	2300
Illuminating Coal Gas.....	.035	650	1200	5.85	9.00	80	285	2900
Water Gas (Uncarb.).....	.044	290	.....	2.20	3.60	.....	.....	.....
Water Gas (Carb.).....	.....	500	.....	5.15	8.50	.....	.....	2500
Blast Furnace Gas.....	.080	94	1560	.70	1.10	170	.....	2000
Coke Oven Gas.....	.042	520	.....	5.40	7.50	.....	.....	2500
Gasolene (85° B.)*.....	5.42 per Gal.	19,000 per Lb.	1050	.....	260 per Lb.	60 to 85	245	1865
Gasolene (75° B.).....	5.69	19,000	925	.....	260	60 to 85	360	2950
Gasolene (68° B.).....	5.89	19,000	910	.....	260	60 to 85	410	3160
Kerosene (48° B.).....	6.55	19,000	945	.....	260	30 to 85	285	.....
Alcohol (Grain), 100% pure....	6.625	11,700	.....	.....	111.5 per Lb.	180	450	.....

(*) 85° B. indicates the specific gravity of the liquid as measured by the Beaumé Hydrometer.

(†) These values are approximate, varying with the chemical composition of the fuel, and with the method of burning it.

Table No. 1

that every particle of explosive material receives its proper amount of oxygen. The actual proportion of air is also influenced by the practical conditions of pressure and temperature at the instant of the explosion. We will find in the table giving the properties of fuels that the actual volumes of air required to burn one cubic foot of any fuel are much greater than the corresponding theoretical values.

TEMPERATURE AND PRESSURE REQUIREMENTS.

We have so far assumed that the fuel possessing a greater heating value will serve as a more efficient material for combustion. According to this theory, a **rich fuel** is more efficient than a **lean fuel**. In actual practice we find this superiority of rich fuels to be considerably reduced on account of the following conditions:

(1) Since the richer fuel requires more air for complete combustion, the explosive mixture made up of such a gas contains less combustible material per stroke than would be admitted with a smaller proportion of air, so that the actual calorific values of the various explosive mixtures are more nearly equal.

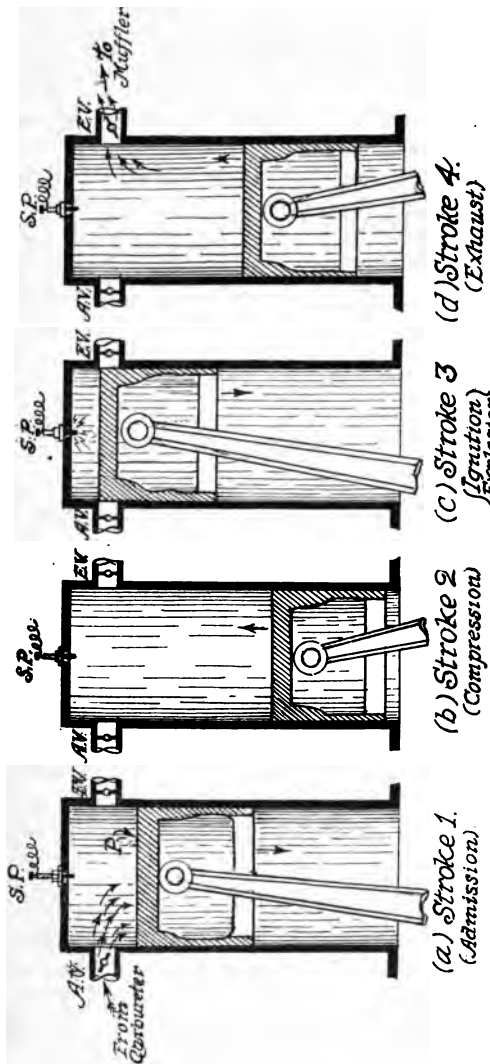
(2) The working efficiency of the mixture depends upon the rate of its burning, termed the rate of **flame propagation**, which is increased in a gas by compressing it before ignition. The rich

fuels cannot be compressed as highly as lean fuels on account of the rapid rise in temperature which is developed during compression, tending to ignite the richer gas more readily before the proper time for explosion. As a result of this, the richer fuels must be operated at lower pressures, thereby losing some of the advantages of a higher rate of flame propagation that are made possible with leaner fuels.

This apparent discrepancy between theoretical and actual heat-values of fuels might be illustrated by the following case: The heat-value of natural gas (in B. T. U. per pound) is about eight times the value of producer gas, but its actual cylinder efficiency is only about 40% to 50% greater as compared with a mixture using producer gas.

In general, we find, that if we limit the amount of compression of the gas mixture to a point where the temperature developed will cause ignition, the actual heating value of the mixture will vary directly as its compression. The temperature of ignition is lower in a fuel having a higher calorific value, which means that a gas engine using a rich fuel must be operated at a lower compression.

The practical compression used in an ordinary gasoline engine is about 70 lbs. per square inch, its ignition temperature being about 925° F. After the explosion takes place the heat developed raises the temperature to about 2900° F. This gain in heat results in an increase in pressure up to



Legend - A.V.-Admission Valve. E.V.-Exhaust Valve. S.P.-Spark Plug. P.-Piston.

Fig.1.-The Four-Stroke Cycle.

about 360 lbs. per sq. in., which acting upon the piston supplies the motive power to the engine.

THE GAS ENGINE CYCLE.

We are now in position to follow briefly the complete series of events taking place in the gas motor from the time the fuel is supplied to it until its motive power is developed. As a familiar case we will take the ordinary gasoline motor. The fuel, in the form of a liquid distillate of petroleum is admitted to the **carbureter**, where it is vaporized and mixed with air in proper proportion to form an explosive gas. This gas is made up of hydrogen and carbon contained in the gasoline, and oxygen and nitrogen which form the constituent parts of air. This mixture is drawn into the cylinder of the engine by suction due to the partial vacuum created in the cylinder by the piston. This period is called the **admission**. (See Fig. 1.). After the mixture is drawn in, the piston reduces the volume of the gas by a return stroke, this action being termed the **compression**. When this is completed the gas is ignited either by its own compression, or by an external agency such as a hot tube, an electric spark, etc. The **ignition** of the gas causes its explosion, or rapid combustion, as a result of which the carbon combines with the oxygen, forming the gases carbon monoxide and carbon dioxide; the hydrogen combines with the oxygen, forming water vapor, and some of the hydrogen

and most of the nitrogen are left in their original state.

The explosion develops in these gases the pressure which gives the motive power to the piston. Finally the burned gases are forced out of the cylinder during **exhaust**, and the engine is ready for the beginning of a new cycle of operations.

To summarize, the gas engine cycle, considering the cylinder only, is made up of the following events:

- | | |
|-----------------|-------------------------|
| (1) Admission | (4) Explosion and Power |
| (2) Compression | (5) Exhaust |
| (3) Ignition | |

Fig. 1, is a simplified diagram showing the four strokes of the piston required to complete the cycle of the so-called "Four-Cycle Engine."

THE INDICATOR DIAGRAM.

By attaching to the cylinder of any engine an instrument called the **indicator** we can obtain a diagram showing the conditions of pressure and volume of the working fluid of the motor at any point of its cycle. The vertical distances in the Indicator Diagram represent the pressures in lbs. per sq. inch, and the horizontal distances correspond to the movements of the piston, which determine the volume of the gas at any instant.

Referring to Fig. 2, we find that the cycle of an ideal engine, in order to utilize the greatest possible portion of its available heat, is made up of

piston strokes of unequal lengths so as to provide for the **complete expansion** of the burned gases before they are exhausted. Line 1-2 represents the admission of the mixture, 2-3 is compres-

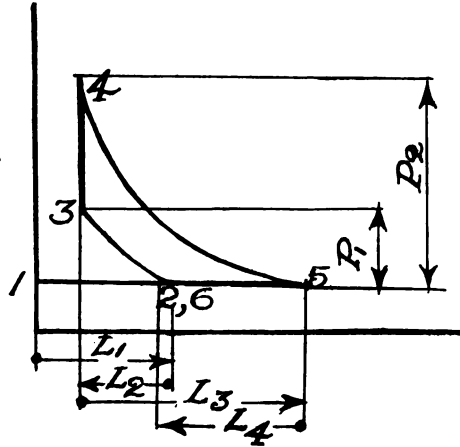


Fig. 2. Indicator Diagram of Ideal Engine with unequal strokes.

sion, 3-4 is the rise in pressure due to the explosion, 4-5 is the expansion during the power stroke, and 5-6 is the exhaust. The lengths and directions of the four strokes (assuming a four-cycle engine) are shown by the arrows L_1 , L_2 , L_3 , and L_4 ; the compression at the point of ignition is indicated by P_1 , and the pressure developed after the explosion is represented by P_2 .

Fig. 3 is the Indicator Diagram of an ideal en-

gine having four equal strokes to the cycle. In this case the expansion is carried down only to pressure P_3 , which is higher than the exhaust pressure, so that a part of the working capacity of

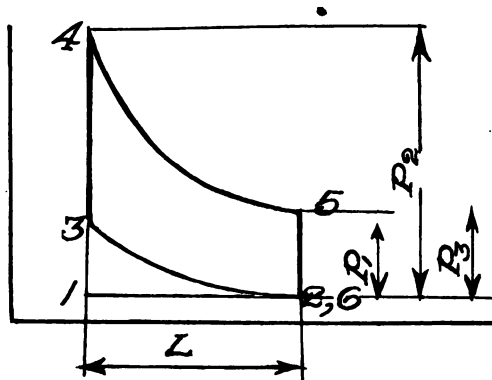


Fig. 3. Indicator Diagram of Ideal Engine with equal strokes.

the gas is thrown away. The advantage of this cycle lies in the simpler design and operation of a motor having equal piston strokes.

Fig. 4 represents the actual indicator card of a typical gas motor having four equal strokes to the cycle. The curves are not as sharp as in the ideal cycle, due to a more gradual action of the valves and the piston, and the lower flat curve 1-2-6 represents lost work on account of **back pressure** during exhaust.

EFFECT OF VARYING GAS MIXTURES.

By increasing the proportion of air per unit volume of fuel we obtain a weaker mixture having a higher ignition temperature. This tends to decrease the heat value of the mixture and it delays the explosion. By diluting the gas still further with air we finally reach the point where the mixture becomes so weak that it will not explode at all.

On the other hand a mixture that is too rich in fuel does not contain enough oxygen for a complete combustion. If the proportion of air to gas is made very small, this will also prevent explosion. This shows that any departure from the correct mixtures of gas and air is not practicable, except within narrow limits, since very poor or very rich mixtures cannot be exploded.

EFFECT OF VARYING GAS SUPPLY.

The length of stroke in every gas motor is constant; consequently, the gas compressed in the upper part of the cylinder, known as the **combustion chamber**, has a definite volume in every engine. By admitting a greater quantity of gas into the cylinder we crowd more explosive material into the same space, thus raising its pressure. By throttling the mixture down through a regulating valve we lower its compression. The effect of throttling the gas supply is, therefore, to

reduce the pressure during the entire admission stroke, causing a considerable loss of power in the form of wasted or **negative work**. (See Fig. 4).

EFFECT OF ADVANCING AND RETARDING THE SPARK.

From the previous discussion of pressure requirements in a gas motor we found that, within certain limits, the heating value of an explosive

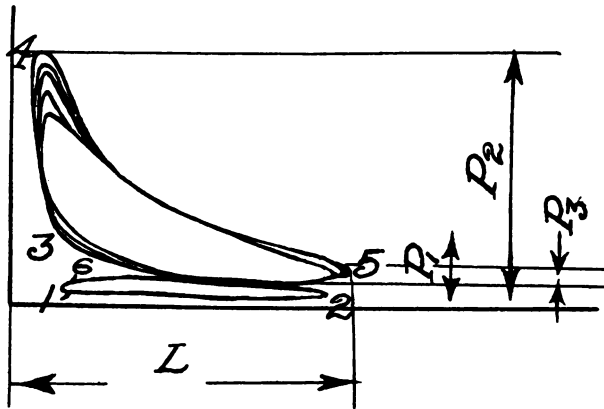


Fig. 4. Indicator Diagram of Typical Gas Engine.

mixture is increased by greater compression. It is, therefore, important that ignition should take place at the instant of maximum pressure, which is

just at the end of the compression stroke. The effect of advancing the spark too far is to fire the charge **before** the end of the compression stroke. This is known as **preignition** and it causes a loss of power and a strain in the working parts of the engine. The effect of retarding the spark is also to reduce the power output of the motor by lowering the pressure at ignition and by retarding the **rate of combustion**, causing a greater loss of heat to the cylinder walls.

REGULATION OF GAS ENGINES.

The speed of a motor at any instant depends upon two factors, viz: The power output and the load. With a uniform load the speed will increase with the increase in power; with a constant power output, the speed will slow down when the load is increased. This, therefore, suggests two principal methods of regulating the speed of gas-motors:

1. By regulating the load on the motor, which is accomplished in the automobile engine by applying the brakes. This is used only in emergencies, as it is wasteful both in power and material.

2. By regulating the power output of the engine through some automatic **governor**, operating on any of the following principles:

- (a) Regulating the proportion of air and gas in the mixture.

- (b) Throttling the supply of the mixture.

(c) Omitting the supply of fuel during some of the engine cycles.

(d) Retarding Ignition.

As was pointed out before, the effect of regulation is to increase the waste in power.

RATING.

The rate of doing a certain amount of mechanical work is termed **power**, which is measured in ft.-lbs. per minute.

The standard unit of power is the **horse-power** written H. P. which is equal to 33,000 ft.-lbs. per minute.

To illustrate, if a certain motor is capable of moving a load against a resistance of 330 lbs. through a distance of 4,000 ft. in two minutes, its rated H.P. is equal to:

$$\frac{330 \times 4000}{2 \times 33000} = 20 \text{ H.P.}$$

In general, the HP. of any engine can be computed

by formula: $\frac{F \times D}{t \times 33,000} = \text{H.P.}$ where **F** is the

force in lbs. and **D** is the distance in feet covered in **t** minutes.

In the gas engine the **force** is the total pressure against the piston, which is equal to the mean pressure per stroke in lbs. per sq. inch multiplied

by the area of the piston in sq. inches. The mean pressure varies with different fuels, with the type of motor and the conditions of its operation. The **distance** depends upon the length of stroke (in ft.), and the time depends upon the speed of the motor, or the number of strokes per minute.

For ordinary automobile motors, the rating is computed by the following approximate formula:

$$\text{H.P.} = \frac{d^3}{2.5} \times n,$$

where **d** is the bore in inches and **n** is the number of active cylinder ends.

EFFICIENCY.

The ratio between the output and supply of energy in any engine is called its **efficiency**, and it is usually expressed in the form of a percent. Thus, an efficiency of 100% would indicate that there were no losses in that engine, and that the total available heat of the fuel was transformed into useful mechanical work. This ideal condition is never attained in any practical engine.

In the gas motor we distinguish between the power developed in the cylinder as shown by its indicator diagram, and the power delivered at the driving pulley, termed the **brake H.P.**

The ratio between the **indicated H.P.** and the energy contained in the fuel as shown by its calo-

rific value is called the **indicated thermal efficiency** of the motor.

By comparing the power output at the brake with the indicated H.P. we get the **mechanical efficiency** of the motor.

The total efficiency of the engine, known as the **thermal efficiency at the brake** is the ratio between Brake H.P. delivered, and the B.T.U. supplied by fuel, expressed in Ft.-lbs. per minute.

The efficiencies of gas-motors vary widely with different types, with the character of their fuels, the methods of their operation, atmospheric conditions, etc.

The thermal efficiencies at the brake of gas engines using producer gas vary from 20% with a power output of 5 HP. per cylinder end, up to about 26.2% with a power output of 120 HP. per cylinder end.

With modern gasoline engines the usual range in efficiency is between 16% and 20.5%. This shows that with all the modern improvements, we are still in the very infancy of gas-motor development.

QUESTIONS ON CHAPTER I.

1. What is the equivalent Fahrenheit temperature of 60° C? 40° C? 100° C?
2. How many Ft.-lbs. of work can be developed from a pound of fuel having a heating value of 19,000 B.T.U. per lb., assuming no losses?

3. How many cubic ft. of air per minute should be used for properly operating a motor running 20 miles on a gallon of gasoline (75° B), at an average speed of 30 miles per hour? (See Table 1.)

4. What are the events of a complete gas engine cycle?

5. What condition limits the amount of practical compression of a gas-motor?

6. What are the effects of regulating the speed by retarding ignition?

7. A four-cylinder automobile motor having a bore of 4 inches, and a 5 inch stroke, is running at 1200 R.P.M. and has a mean effective pressure of 68 lbs. per sq. inch. Find its rated HP. by the exact formula.

8. Compute the HP. of the above engine by the approximate formula.

9. A motor is using a high grade gasoline (85° B) at the rate of one gallon per hour. What is the power supplied to the engine?

10. If the engine in question 9 develops 10 HP. (indicated), what is its indicated thermal efficiency?

11. Assuming a mechanical efficiency of 80%, find the HP. delivered at the brake of the above motor.

12. What is the thermal efficiency at the brake of the above motor?

CHAPTER II

THE GAS SUPPLY.

Any substance containing a large percentage of carbon and hydrogen in a form that will readily combine with oxygen can be used as fuel for internal combustion engines. The most common materials used for fuels in modern gas motors are as follows:

A. Solid Fuels:

1. Coals
 - (a) Anthracite (hard coal, high in fixed carbon),
 - (b) Bituminous (soft coal),
 - (c) Lignite (lowest in fixed carbon).
2. Coke

B. Liquid Fuels:

1. Petroleum Products
 - (a) Gasoline,
 - (b) Naptha,
 - (c) Kerosene,
 - (d) Crude oils.
2. Alcohols
 - (a) Grain,
 - (b) Wood.

C. Gas Fuels:

Natural Gas,
Acetylene.

VAPORIZATION OF SOLID AND LIQUID FUELS.

The solid and liquid fuels must first be changed into gases, or **vaporized** before they can be admitted into the cylinder of a gas engine. The gases formed by vaporizing coal or coke can be classified as follows:

1. **Illuminating Coal-gas**, which is distilled from rich bituminous coal, and is made up of about 50% of hydrogen, 35% of methane (a very common hydrocarbon) and about 6% of partially burned carbon in the form of carbon monoxide. Coal gas usually contains also a small portion of carbon dioxide and nitrogen.

2. **Illuminating Water-gas**, which is also distilled from bituminous coal, with the addition of steam supplied to the fuel during the heating process. It contains a smaller percentage of hydrogen and methane and a larger amount of carbon monoxide.

3. **Producer gas**, made by partial combustion of anthracite, bituminous coals or coke, containing about 13% of hydrogen and 25% of carbon monoxide. These are diluted with over 50% of nitrogen and other admixtures, resulting in a gas having a relatively low heating value.

To this class also belong:

4. **Blast-furnace gas**, which is a by-product of metallurgical industries, and

5. **Coke-oven gas.** Both of these gases are poor in free hydrogen, and contain about 60% of nitrogen.

Among the liquid fuels, the petroleum products are the most prominent and the most widely used for operating gas-motors. Their advantage lies in the fact that they are readily vaporized at atmospheric pressure, they have high calorific values and they can conveniently be carried in tanks for use of motor-vehicles, boats, aeroplanes, and other small movable engines, where the coal product are practically out of the question.

PHYSICAL PROPERTIES OF GASOLINE.

The various grades of petroleum products are primarily distinguished by their **Specific Gravities**, or their weights per unit volume compared with water as a standard. The specific gravity of any liquid can readily be measured by the aid of an instrument, called a **hydrometer**.

The principle of the hydrometer is based upon the fact that when a solid body is immersed in any liquid it will submerge to a depth at which the weight of the displaced liquid will equal to the weight of the body. Since the weight of the displaced liquid determines its uplifting force, it follows, that if the same body be placed in a lighter liquid, its lifting force will be smaller, and the solid will be submerged lower than if placed in a denser substance. If this body has a uniform cross-section

vertically, then the denser the liquid, the greater will be the height projecting above the surface, provided the body always maintains its upright position. This is accomplished by placing at the bottom of the floating body a heavy weight not large enough to sink it, but just sufficient to lower its center of gravity and thus to keep it in an upright position. If the vertical height of such a float is graduated so that the projecting portion above the surface gives the value of its specific gravity directly, then we have the typical hydrometer, as shown in Fig. 5.

For testing gasoline the **Beaume hydrometer** is used, on which a reading of 10° equals to the specific gravity of water which is **1.000**.

The physical properties of petroleum products are given in Table 2, from which we find that gasoline has a gravity from about 70° to 85° Beaume, a heating value of about 19,000 B.T.U. per pound, and a boiling point of about 150° F. It is very **volatile** which means that it vaporizes readily when exposed to the air.

TESTS.

The physical properties of gasoline given above suggest a number of tests, such as the determination of its gravity by means of the hydrometer. Care should be taken to allow for the change in the density of gasoline due to heating or cooling, by measuring the temperature of the

liquid during the test and making proper corrections in the hydrometer reading.

A very common test is the so-called **flash-test**, which consists of heating the liquid gasoline and

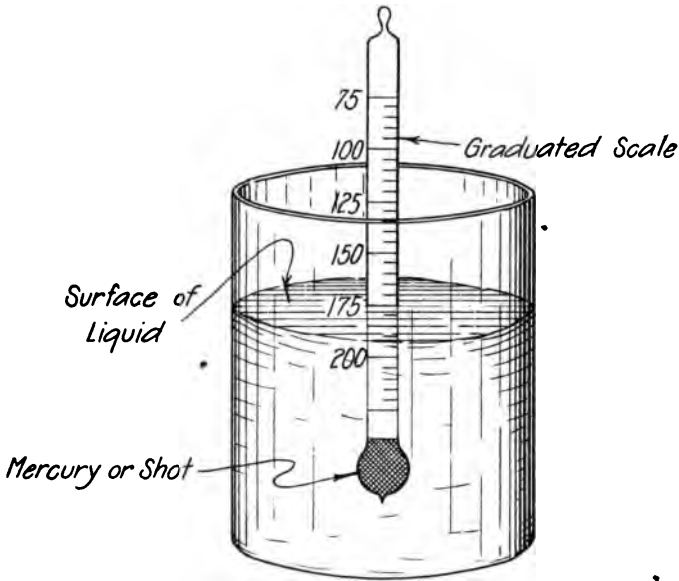


Fig. 5. The Hydrometer.

applying an open flame to its surface. The vapor formed at the surface of good gasoline should flash, or catch fire at about 70 to 75 degrees Fahrenheit.

<i>Name of Product</i>	Spec. Grav.	Grav. Baume	Pounds per Gallon	Heat Value B. T. U.	Boiling Point Fahr.
Rhigolene	6365	90.	5.303		85°
Light Gasoline	6655	81.	5.544	19,000	150°
Stove Gasoline	6820	76.	5.682		
Benzoline	6920	73.	5.765		
Naphtha, C.	7060	69.	5.882		180°
Naphtha, B.	7240	64.	6.032		220°
Naphtha, A	7430	59.	6.190		300°
Perina Kerosene	7840	49.	6.532	20.018	
W. Va. Crude Oil	7925	47.	6.602	20.030	
Kerosene	8015	45.	6.677		350°
Ohio Crude Oil	8065	44.	6.719	20.058	
Cal. Ref. Oil	8110	43.	6.756	19.802	
Light Penna Crude	8155	42.	6.794	19.933	
W. Va. Crude Oil	8205	41.	6.836	19.850	
Russian Distillate	8250	40.	6.873	21.060	
Penna. Crude Oil	8345	38.	6.952	19.782	
Mineral Sperm Oil	8440	36.	7.031		425°
Kansas Crude Oil	8490	35.	7.073	19.724	
Solar Fuel Oil	8545	34.	7.119	19.580	
Ills. Crude Oil	8595	33.	7.160	19.380	
Cal. Distillate	8650	32.	7.206	19.550	
Crude Oil from Galicia	8700	31.	7.248	18.150	
Penna. Distillate	8755	30.	7.294	19.210	
Neutral Oil	8815	29.	7.344		575°
Penna. Distillate	8870	28.	7.390	19.200	
Texas Crude Oil	8930	27.	7.440	19.250	
Texas Crude Oil	8990	26.	7.490	19.350	
Light Lub. Oil	9045	25.	7.536		580°
Texas Crude Oil	9105	24.	7.585	19.280	
Cal. Crude Oil	9165	23.	7.635	18.575	
Ohio Fuel Oil	9220	22.	7.681	19.100	
Mexican Huasteca Crude	9280	21.	7.731	18.320	
Russian Crude Oil	9400	19.	7.831	19.440	
Huasteca Topped Crude	9465	18.	7.885	17.950	
Heavy Lub. Oil	9530	17.	7.939		630°
Heavy Mex. Fuel Oil	9595	16.	7.994		
California Crude Oil	9655	15.	8.044	18.550	
Mexican "Ebano" Crude	9720	14.	8.098	17.200	
Java Crude Oil	9790	13.	8.156	18.330	
Crude from "Ogaio"	9860	12.	8.214	18.150	
Mexican "Ebano" Crude	1.000	10.	8.331	18.550	

Compiled by De La Vergne Machine Co., 1159 E. 138th St., N. Y.

*Table No. 2
Properties of Petroleum Products.*

A simple practical test of gasoline consists in allowing a small portion of the liquid to evaporate from the hand and noting its **volatility**. Good gasoline should evaporate quickly and leave no appreciable odor.

GRAVITY SUPPLY SYSTEM.

In gas motors using gasoline, the fuel is usually stored in tanks located above the mixing valve or carbureter, so that the liquid flows down by gravity to the carbureter to be mixed with the proper proportion of air. For motor-vehicles, boats and aeroplanes, the supply of gas must be sufficient for an average length of travel, which for automobiles is about 75 miles, calling for a minimum tank capacity of about 5 gallons. In modern cars the tank capacity runs up to about 30 gallons. For aeroplanes provision should be made for about six hours flight, at an average speed of 50 miles per hour. Assuming a gasoline consumption of 15 miles per gallon, the minimum required tank ca-

$$\text{capacity for aeroplanes is } \frac{50 \times 6}{15} = 20 \text{ gallons.}$$

In all gravity supply systems the feed pipe extends about an inch over the bottom of the tank to prevent any foreign matter from getting into the carbureter or piping and thus clogging up the supply of fuel to the engine. It is also advisable to

have some form of a strainer at the gasoline supply plug to keep it absolutely pure.

Between the tank and the carbureter there should be located a tight-fitting valve so that the gasoline could be shut off in cases of fire in the system, or for repairing and adjusting the carbureter.

ADVANTAGES.

The gravity system has the advantages of simplicity, reliability, and high efficiency for small motors and for vehicles traveling on level roads on short trips in or around town.

DISADVANTAGES.

In case of larger motors, or for automobiles touring in the country where high grades are encountered, the gravity system is not reliable, since on climbing a hill the car may have an inclined position, forcing the carbureter to a higher level than the tank, thus automatically cutting off the supply. In such a case the car has to be turned around at the foot of the hill and backed up, which is very troublesome. For aeroplanes or dirigible balloons the gravity system is practically out of the question, since in this case we must have an absolutely reliable supply of fuel at any position of the machine.

PRESSURE SUPPLY SYSTEM.

In order to provide the engine with a more positive gas supply, the back pressure from the engine exhaust is often utilized in forcing the gasoline from the tank to the carbureter. This is known as the **Pressure or forced feed supply system**, shown in Fig. 6 in the form of a simplified diagram of connections.

Referring to Fig. 6, the pressure passes from the engine exhaust pipe to the top of the gasoline tank through a small pipe provided with a check valve to prevent the gasoline from feeding back to the engine. When the motor is running at very low speed, or on starting, the pressure is maintained by means of an auxiliary air pump provided with a **pressure gauge**, or an instrument used for indicating the pressure in the system in lbs. per sq. inch above the atmospheric. This pressure, applied at the top of the tank, forces the gasoline out through a pipe leading from the bottom of the tank to the gasoline valve of the carbureter. (See Fig. 6.) After being mixed with air and vaporized in the carbureter, the gas is drawn in to the admission valve of the engine by the partial vacuum created in the cylinder at the end of the exhaust stroke.

Some gas motors equipped with the pressure supply system have also a small auxiliary gasoline tank placed close above the carbureter so as to

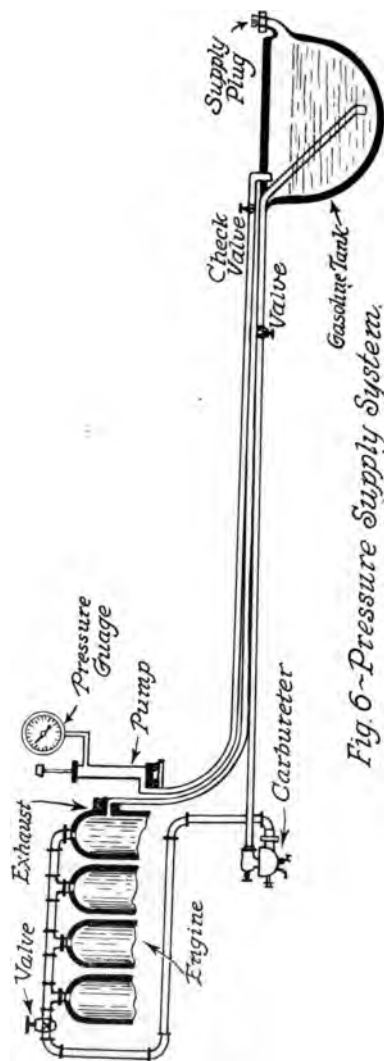


Fig 6-Pressure Supply System.

supply the fuel by gravity in case the pressure system should break down.

THE FUNCTION OF THE CARBURETER.

The fuel-mixing device or the **carbureter** is one of the most important accessories to the modern gasoline motor, since it performs the double service of vaporizing the gasoline and mixing it with a proper proportion of air for efficient combustion in the engine. There is a great variety of carbureters now used which perform these functions reasonably well within a limited range of engine speeds. But for some engines this range is not satisfactory, as what may be right for high speeds is wrong for low speeds, and vice versa.

According to the theory of their operation all the carbureters may be classified as follows:

1. **The surface carbureter**, in which the air comes in direct contact with the surface of the volatile liquid until it is saturated. This type is now obsolete as it is not reliable and tends to clog up the supply system.

2. **The Filtering Carbureter** which forces the air through the volatile liquid and in this manner makes a more or less perfect mixture by absorption.

3. **The Float Feed Carbureter**, where the gasoline is sprayed through a nozzle into a separate chamber where it is mixed with air. This type is most generally used at the present time.

Some of these types are operated by a special form of mechanism, in which case the operator has to regulate the sizes of air and gas passages to meet the requirements of varying speeds, road grades, ignition, loads, etc.

In other types, the action of the carbureter may be more or less independent of the operator, by automatically increasing or decreasing the air supply in accordance with the requirements of the engine.

Fig. 7 is a cross-sectional view of a very common float-feed type, known as the **Schebler-Wheeler Carbureter**. It consists of the following main parts: the floating valve made up of the mechanism W, R and C (See Fig. 7) ; the spraying Nozzle P; the Needle Valve N; the Mixing Chamber M; the air supply system A, V, G and E; and the Throttle Valve arrangement T and L.

FLOATING VALVE.

The function of the floating valve is to control automatically the supply of gasoline flowing either by gravity or by forced feed from the tank through **pipe S** so as to maintain the level of the liquid in the **float-chamber F** nearly constant. This is accomplished by means of a very light **float C** made of either cork, light wood, or hollow metal, which rises and falls with the level of the liquid in the float chamber. When the supply of gasoline is too rapid, the float C is raised, carrying up with

it **lever arm R** which is free to move about pivot **O**. This arm comes in contact with the **spindle-valve W** forcing it to the narrow passage of the supply pipe and thus automatically shutting

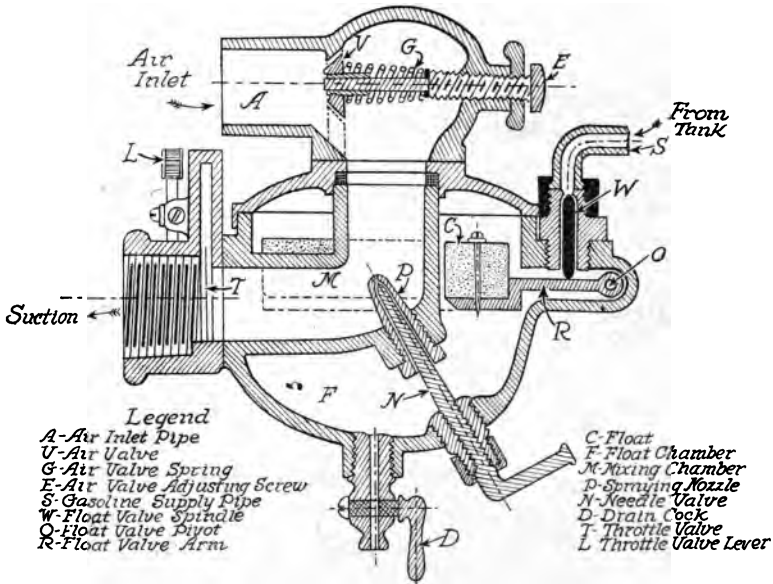


*Fig. 7. Float Feed Carburetor
of the Schebler-Wheeler Type.*

off the flow of gasoline. When the gasoline is drawn from the float chamber its level falls and the valve is lowered, opening the passage in the supply pipe and allowing the fuel to enter the carburetor.

SPRAYING NOZZLE.

The liquid gasoline is admitted to the **mixing chamber M** through the small passages of the **spraying nozzle P** in such a manner as to atomize the liquid, or divide into very minute particles ready for absorption by the air.

THE NEEDLE VALVE.

The rate of flow through the spraying nozzle is controlled by a **Needle Valve N**, which restricts, more or less, the gas passage in the nozzle. This valve can be easily adjusted by means of the handle as indicated in Fig. 7, and it should always be turned to a position that will give a proper amount of gas supply for the varying conditions of speed and load of the motor.

MIXING CHAMBER.

The fine spray of gasoline comes in contact with air in the **mixing chamber M**, where it is finally vaporized and mixed in proper proportion to form the explosive gas required by the engine. In order to secure quicker and more positive generation of gas, the air admitted to the mixing chamber is pre-heated by passing it close to the engine exhaust. This helps to vaporize the liquid particles of gasoline faster, and it secures a more uniform explosive mixture. The proper proportions of gas

and air have been more fully explained in Chapter I, where it was pointed out that the heating value of the fuel depends largely upon the correct quantities of air and gas contained in the mixture.

AIR SUPPLY.

The proper quantities of air are secured by an automatic **air-valve V** which controls the size of the passage from **air intake pipe A** to the mixing chamber. This is accomplished by the **coil-spring G** which tends to hold the valve seat tight against the intake pipe and which is compressed by the suction of air created by the partial vacuum in the engine cylinder. The greater the air suction, the more the coil-spring is compressed and the larger becomes the air passage from intake to mixing chamber. Since this suction is increased with the speed of the motor, it is evident that at greater speeds, requiring more fuel, the air supply is automatically increased, and at lower engine speeds the supply of air is correspondingly diminished. The tension of the air valve spring can be controlled by the **adjusting-screw E** so that the proper amount of air is admitted under varying conditions of load and speed. The proper adjustment of the air valve is secured when the mixture gives, at all speeds, the maximum explosion, which is the most efficient form of burning the fuel.

THROTTLE VALVE.

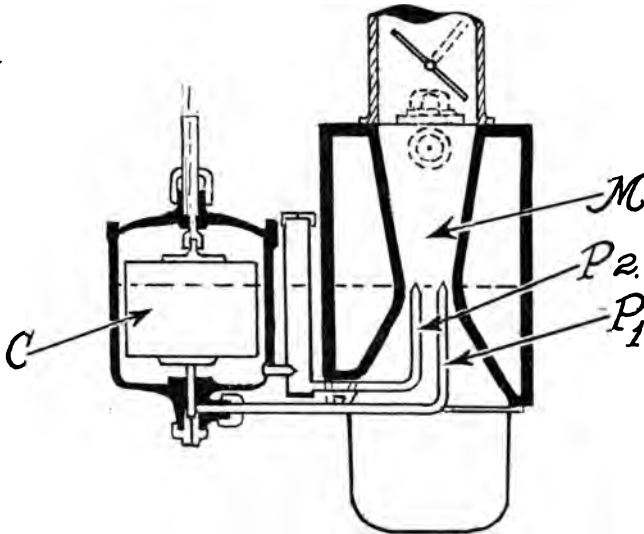
The final mixture of gas and air is drawn into the engine cylinder from mixing chamber M to the suction pipe through the **throttle valve T**, which controls the quantities of the mixture entering the admission valve of the engine, by varying the size of opening in the suction pipe. The throttle valve is operated by means of links connected to the **operating lever L**, which furnishes a practical method of governing the speed of the motor by controlling the quantity of gas supplied to the cylinder, as pointed out in Chapter I.

In starting the engine it frequently happens that the gasoline supply is insufficient on account of the initial suction not being strong enough to force the liquid through the spraying nozzle and thus to lower the float-valve enough so as to admit more gasoline into the carbureter. This is avoided by forcing the spindle-valve W down by means of a small piston provided for that purpose. This forces the float-valve to the open position and the float chamber of the carbureter is filled or **flooded** with gasoline, delivering a sufficient supply of fuel to start the engine and to bring it to full speed, after which the valve-spindle is released.

COMMON TYPES OF CARBURETERS.

The ordinary float-feed type of carbureter has the disadvantage of not always supplying the

quantity of gas proportional to the demands of the motor. This is remedied in some types by providing an additional air inlet to the carburetor which could be controlled by the operator. In



Legend:
C-Float. M-Mixing Chamber. P₁ and P₂-
Spraying Nozzles

Fig. 8-Multiple Spray Float Feed Carburetor.

other cases it is accomplished by providing additional spraying nozzles, as shown in the sketch of a **multiple spray carburetor** in Fig. 8, where C is

the float, P_1 and P_2 are the two spraying nozzles, and M is the mixing chamber.

A very common type of carbureter, operating on the principle of **aspirating** the gasoline without the aid of a float, is illustrated in Fig. 9. Referring to Fig. 9, the gasoline enters the supply pipe P and passes through a conical spindle valve C which is held up vertically by light spring S . The conical valve C is drawn down by suction from the cylinder, in opposition to the action of the spring S tending to force it up. This slight opening of the conical valve admits to the mixing chamber M a certain amount of gasoline which is drawn by aspiration of the air entering through the inlet valves located in the upper part of the mixing chamber. The vaporized mixture passes from mixing chamber M to supply chamber N through a disk valve V which is fastened to the middle of the spindle and fits loosely in a sleeve. From N the fuel is drawn into the cylinder through pipe T . The mixing chamber is heated by circulating around it, in a separate jacket, the hot products of combustion from the engine exhaust, admitted through pipe E . The amount of gasoline supplied through pipe P can be regulated by means of a hand wheel as shown in Fig. 9.

This carbureter has the advantage of doing away with the uncertainty of the float-feed devices when used on motor cars or for aviation, where the shaking of the machine disturbs the proper

operation of the float. It is best adapted for motors running at moderate speeds, as with very

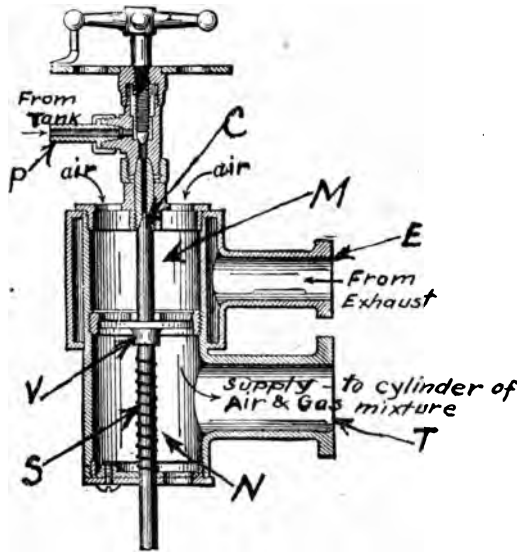


Fig. 9

Automatic Carbureter with Spring-Valve Feed

LEGEND

P—Gasoline Supply Pipe	M—Mixing Chamber
C—Conical Valve	N—Supply Chamber
V—Disk Valve	T—Supply Pipe
S—Valve Spring	E—Exhaust Connection

high speeds the valves cannot overcome their inertia fast enough to supply the motor with sufficient power corresponding to the greater speed.

GAS SUPPLY TROUBLES.

All the common troubles of gasoline motors caused by failure of the fuel supply system can be classified in the following manner:

I. Troubles due to presence in the gasoline of **foreign matter**.

1. Chemical impurities.
2. Dirt.
3. Water.

II. Troubles due to **shortage of gasoline** supply.

1. Empty tank.
2. Shut-off cock closed.
3. Failure of gravity flow.
4. Failure of pressure in forced feed system.
5. Closed Needle Valve.
6. Supply system clogged up.
7. Float valve sticking.
8. Spraying Nozzle choked.

III. Troubles due to **Excess of Gasoline** supply.

1. Failure of float valve to close.
2. Submerged float.
3. Needle valve open.

IV. Troubles due to **shortage of air** supply.

1. Obstructions in air inlet pipe.
2. Air valve sticking.

The presence of foreign matter in gasoline reduces the heating value of its mixture with air, and in extreme cases of accumulation of large quantities of dirt or water, it may entirely prevent the explosions in the cylinder.

Shortage of gasoline will cause weak mixtures, resulting in decrease in power output of the motor.

An excess of gasoline will weaken the power output and efficiency of the engine, since the supply of oxygen will not be sufficient for a complete combustion of the fuel. This will also result in a deposit of a layer of carbon in the cylinder and engine valves, which lowers the general efficiency of the motor and may ruin it if not removed periodically.

An excess of air supply affects the motor in a similar manner as a shortage of gasoline.

REMEDIES.

In order to prevent the many engine troubles due to impure gasoline it is necessary to take every precaution to remove all the impurities before they can reach the supply system of the motor. The gasoline should be carefully tested for the presence of other chemicals, or if this is not practicable for the small consumer, it is important that the fuel be purchased from a reliable concern.

Provision should be made to strain the gasoline entering the tank by means of fine wire screens and chamois skins to remove any dirt or water that might be contained in it. The tank should often be drained through the drain-cock provided for that purpose, and it should be periodically cleaned of all residue, dirt, water, etc., collected at the bottom.

It is important, before starting on a long trip in a motor-vehicle, boat, or flying machine, to ascertain that both the main and auxiliary supply tanks are filled, and the shut-off cocks are open and secured in such a manner that the shaking of the machine will not jar them shut.

In case of failure of the flow by gravity on steep grades, which is caused by the carbureter being at a higher level than the tank, the machine has to be backed up until the top of the hill is reached.

With the pressure supply system, special care must be taken that all piping, valves and connections are air-tight, and the pressure, as indicated by the guage, is sufficient to maintain a steady flow of fuel to the carbureter.

The Needle valve of the carbureter must be carefully adjusted for the proper mixture, and it should be rigidly secured so that it can not be jarred from this position. All foreign matter must be kept out of the carbureter, especially at the float valve and in the parts of the air supply, as any particles of dirt, lodged in the valve seats or

springs will cause the valves to remain open. In case the float is submerged on account of the coat of shellac being worn off (in case of cork floats) or the metal being punctured (in case of hollow metal floats), a new float must be installed, and the carbureter should be carefully adjusted for the proper level of liquid.

Practically all other gas supply troubles can be attributed to clogging up, or to the presence of dirt in the piping and connections, and these can be remedied or avoided altogether by keeping all the parts of the system scrupulously clean and properly inspected.

QUESTIONS ON CHAPTER II.

1. What are the products of combustion of producer gas used as fuel in a gas engine?
2. Using the values in Table 2, find the weight of gasoline having a specific gravity of 75°B, required to fill a 30 gallon tank.
3. What is the pressure of flow in the gravity supply system with the level in the tank being ten inches above the level in the carbureter?
4. What is the function of the auxiliary pump in the Pressure Supply System?
5. What is the function of the Carbureter?
6. How is the supply of gasoline regulated in the float-feed type of Carbureter?
7. How does the speed of the motor affect the action of the Carbureter?

8. What is the advantage of the multiple spray Carbureter?

9. What are the advantages and disadvantages of the Automatic Carbureter with the Spring-Valve Feed?

10. What are the causes of partial or total failure of gasoline supply?

11. What are the effects of excess in gasoline supply?

12. How could dirt and water be excluded from the supply system?

ANSWERS TO QUESTIONS ON CHAPTER I.

1. Using Formula: $F = C \times \frac{9}{5} + 32$, we have:

$$F = 60 \times \frac{9}{5} + 32 = 108 + 32 = 140^{\circ}\text{F.}$$

$$40 \times \frac{9}{5} + 32 = 72 + 32 = 104^{\circ}\text{F.}$$

$$100 \times \frac{9}{5} + 32 = 180 + 32 = 212^{\circ}\text{F.}$$

which is the boiling temperature.

2. The Mechanical equivalent is 778 Ft.-lbs. per B.T.U. Total Mechanical work of 19,000 B.T.U. = $19,000 \times 778 = 14,782,000$ ft.-lbs.

3. Wt. of gasoline used per hour

$$= \frac{30}{20} \times 5.69 = 8.53 \text{ lbs.}$$

With a proportion of 260 cu. ft. of air per lb. we have: volume of air per minute

$$= \frac{8.53 + 260}{60} = 37 \text{ cu. ft.}$$

4. The events of the complete cycle are: admission, compression, ignition, explosion, power and exhaust.

5. The compression can be carried up to the point where the temperature developed by it becomes equal to the ignition temperature of the mixture.

6. Retarding ignition results in decrease of power output, lowering the efficiency, and causing excessive heating of the cylinder walls due to the slow rate of combustion.

7. Referring to the general formula:

$$\text{H.P.} = \frac{F \times D}{t \times 33,000}, \text{ F in this case equals to the}$$

mean pressure per stroke times the area of cylinder bore.

The area of a 4 inch circle = 12.57 sq. in. Assuming the engine to be "Four-cycle," the mean

$$\text{pressure per stroke} = \frac{68}{4} = 17.0 \text{ lbs. per sq. in.}$$

Then $F = 17.0 \times 12.6 = 214.2 \text{ lbs.}$ **D** is the pis-

$$\text{ton speed in feet per minute} = \frac{5}{12} \times 2 \times 1200 =$$

1000 ft. per minute. **t** is in this case equal to one minute.

$$\text{Therefore H.P.} = \frac{214.2 \times 1000}{1 \times 33,000} = 6.5 \text{ H.P. per}$$

cylinder.

The total power of the four-cylinder motor
 $= 6.5 \times 4 = 26.0 \text{ H.P.}$

8. Using the formula:

$$\text{H.P.} = \frac{d^2}{2.5} \times n = \frac{4 \times 4}{2.5} \times 4$$

$$= 25.6 \text{ H.P.}$$

9. Assuming the heating value of the gasoline to be 19,000 per lb., one gallon will contain 19,000 $\times 5.42 \times 778 \text{ ft. lbs.} = 80,123,000 \text{ ft. lbs. of work.}$
 The power supplied to the engine =

$$\frac{80,123,000}{60 \times 33,000} = 40.5 \text{ H.P.}$$

10. The indicated thermal efficiency is

$$\frac{10}{40.5} \times 100 = \mathbf{24.7\%}.$$

11. The power at the brake $= 10 \times .80 =$
8.0 H.P.

12. The thermal efficiency at the brake

$$= \frac{8.0}{40.5} \times 100 = \mathbf{19.7\%}.$$

CHAPTER III.

ELEMENTS OF THE SINGLE CYLINDER ENGINE

The successful operation of any type of gas motor depends upon the following two requirements:

1. The proper proportion of air and fuel necessary for the most efficient explosive mixture.
2. A practical method of compressing and firing the charge after it has been admitted into the cylinder of the engine.

In case the fuel used is a product of coal, such as Producer Gas, Illuminating Gas, etc., it is mixed directly with the proper volume of air by some valve arrangement. For products of petroleum it is necessary to employ a special carbureting device, where the liquid fuel is vaporized and mixed with the correct amount of air.

This mixture of gas and air is compressed by the reciprocating motion of the piston in the cylinder, and it is ignited by means of some outside agency, such as a hot metal or an electric spark.

The ignition causes explosion, which releases the heat stored up in the explosive mixture, tending to expand the gases formed as a result of the combustion. This creates a **pressure** in the com-

bustion chamber, pushing the piston outward and developing the mechanical power of the motor.

The elements of the single-cylinder gas engine are: the **cylinder**; the **piston**; two main openings or **ports**, which may or may not be controlled by **valves**, one for admitting the mixture, and the other for expelling the burned gases; a **connecting rod** and a **crank shaft** for converting the reciprocating motion; and a **fly-wheel** to insure steady rotation of the shaft during the idle parts of the engine cycle.

The other important parts of the gas motor which are separate from the engine proper but are necessary for its operation, are: **The Carbureter** for vaporizing and mixing the fuel; **the Ignition system** for firing the explosive charge; the **Muffler** used for deadening the noise of the escaping burned gases from the cylinder into the atmosphere; and the **cooling system** which is required to cool off the heated walls of the cylinder due to the explosions.

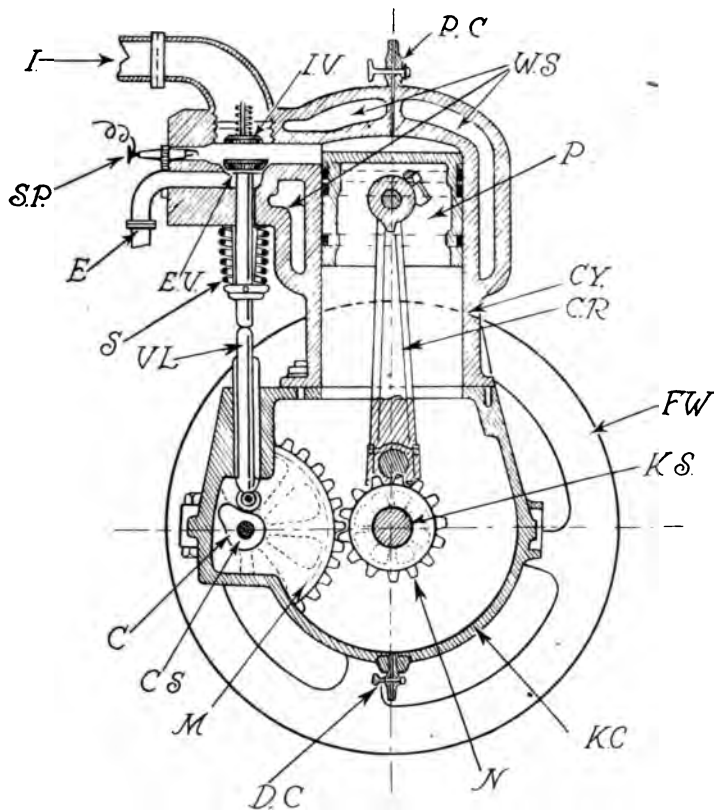
THE FOUR-STROKE SINGLE-ACTING ENGINE

This type of engine is commonly known as the "**Four-cycle Engine**", which is a misleading term, since it actually accomplishes the complete cycle of operations in four strokes, or in two revolutions. The term "single acting" implies that only one end of the cylinder serves as the combustion chamber, to distinguish it from large stationary gas-engines

in which both ends of the cylinder are used to develop power in the same manner as in most types of steam engines.

In the four-cycle single acting motor only one end of the piston is employed to do useful work, and at least two valves are required, one, termed the inlet or **admission-valve**, and the other termed the **exhaust-valve**. The admission valve may be either mechanically controlled, or its action may be automatic due to the partial vacuum created in the cylinder by the outward movement of the piston. The exhaust valve is always mechanically operated from the crank shaft by means of gears and a special mechanism designed to open it just before the end of the **power stroke** and to close it just before the beginning of the admission or **suction-stroke**.

Referring to Fig. 10, which is a cross-section of a Vertical, Four-stroke, single acting engine, the cylinder (CY.) is shown partly surrounded with water spaces (W.S.) provided for cooling the walls by circulating water around them. The piston (P.) is shown at its upper position at the end of the compression stroke, both the admission valve (I.V.) and exhaust valve (E.V.) being closed. The motion of the piston is transmitted by the connecting Rod (CR.) to the crank-shaft (KS.) located in the lower space of the engine frame or in the crank-case (KC.), and directly connected to the fly-wheel (FW.). The mixture is admitted through



Legend		
<i>I</i> - Inlet Pipe	<i>C.R</i> - Connecting Rod	<i>M</i> - Cam Shaft Gear
<i>IV</i> - Admission Valve	<i>FW</i> - Fly Wheel	<i>C</i> - Cam
<i>PC</i> - Pet Cock	<i>KS</i> - Crank Shaft	<i>VL</i> - Valve Lifting Rod
<i>WS</i> - Water Spaces	<i>KC</i> - Crank Case	<i>S</i> - Valve Spring
<i>P</i> - Piston	<i>N</i> - Crank Shaft Pinion	<i>EV</i> - Exhaust Valve
<i>CY</i> - Cylinder	<i>DC</i> - Drain Cock	<i>E</i> - Exhaust Pipe
	<i>SP</i> - Spark Plug	

Fig 10- The Four-stroke Single Acting Engine.

the inlet pipe (I.) and the products of combustion are expelled through the exhaust-pipe (E.). Ignition is provided at the spark-plug (S.P.). The engine is equipped with a pet-cock (P.C.) at the top of the cylinder, and a drain-cock (D.C.) at the bottom of the crank-case. The inlet valve (I.V.) is automatic, operated by suction during the admission stroke. The exhaust valve is mechanically operated from the crank shaft by means of gears M and N, also by cam C mounted on the **cam-shaft** (C.S.) and the **valve-lifting rod** (V.L.). The valve proper (E.V.) is held down on its seat by the tension in the **valve spring** (S.).

Since, in a four-cycle engine, exhaust occurs only once in every two revolutions of the crank-shaft, the gears operating the exhaust-valve have a ratio of 1 to 2, the smaller one being keyed to the crank-shaft and the larger one is placed on the **cam-shaft** (C.S.). The cam is also keyed to this shaft and the gears are meshed or **timed** in such a manner that the cam is just ready to operate the valve-lifting rod when the crank shaft is at an angle of about 10 degrees from its position at the end of the power stroke. This is known as a **lead** of 10 degrees, which is required in order to overcome the inertia of the working parts of the valve before exhaust takes place. A similar lead is provided at the end of the exhaust stroke. For high-speed motors these leads are correspondingly increased.

The action of the vertical Four-cycle engine can be described as follows:

Stroke 1. Piston moving down; exhaust valve closed, admission-valve open by suction. Gas enters the cylinder through inlet pipe (see (a) Fig. 1, also Fig. 10).

Stroke 2. Piston moving up; both valves closed. Gas is compressed in the combustion chamber. (See (b) Fig. 1, also Fig. 10).

Stroke 3. Piston moving down, both valves closed. At the beginning of this stroke ignition takes place. The compressed charge is exploded, and the pressure acts upon the piston. (See (c) Fig. 1). Near the end of the power stroke the cam begins to lift the rod, partly opening the exhaust valve. (See Fig. 10.)

Stroke 4. Piston moving up. Admission valve closed, exhaust valve open. Burned gases escape to the muffler or to atmosphere (see (d) Fig. 1). At the end of the exhaust stroke the cylinder is nearly free from gas and ready for the repetition of the cycle.

THE TWO-STROKE SINGLE ACTING ENGINE.

From the discussion of the Four-cycle motor it is evident that in that type of engine we have only one power impulse during two complete revolutions, or once in every four strokes of the piston. The other three strokes of the cycle are made possible by the action of the revolving fly-wheel which

tends to continue its motion due to inertia. This results in an uneven distribution of power, causing heavy strains in the working parts of the motor and giving a jerky motion to the shaft. This type of engine also requires a complicated valve mechanism, especially for regulating the exhaust. These objectionable features are partly avoided in the **two-cycle motor** but at the price of a lower efficiency, since in this engine, with a doubled consumption of fuel for the same number of revolutions, we only get about 20% more mechanical power.

The two-cycle motor which should be correctly named the **two-stroke single acting engine**, completes all the events of the cycle in two strokes, or in one revolution, by making both ends of the piston perform the function of distributing the gas mixture to and from the cylinder. These motors may be constructed without any valves, using three ports for admitting and exhausting the gas automatically by the reciprocating motion of the piston. In the two-port motors an automatic inlet valve takes place of the third port.

All the two-cycle gas motors can therefore be classified as follows:

1. Single acting three port motor.
2. Single acting two port motor.
3. Single acting with combination of two and three ports.
4. Double acting three port.

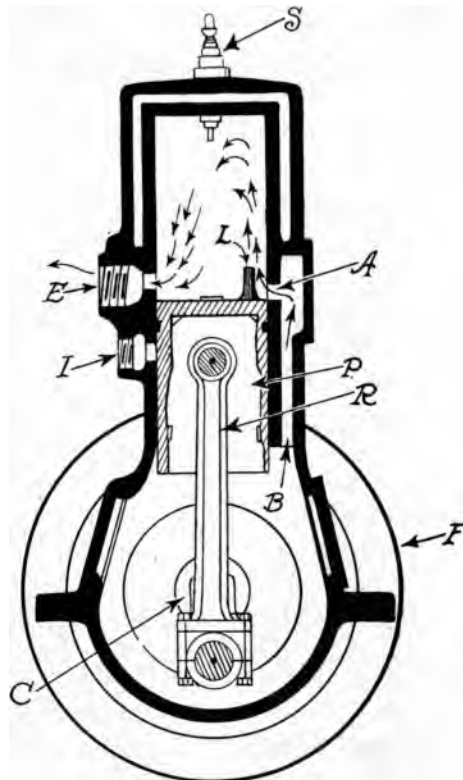
5. Double acting two port.
6. Double acting with combination of two and three ports.

Any of these types may be water cooled or air cooled, horizontal or vertical, single or multiple cylinder, etc.

Fig. 11 is a cross-section of a single acting two-cycle three-port Vertical Water Cooled Engine. Its action is as follows:

Stroke 1. Piston (P) is moving up. Inlet port (I) is closed by the piston. Admission port (A) is still open, allowing the gas under partial compression in the crank case to enter through bypass (B) to the cylinder.

This fresh charge is deflected upward by baffle plate (L) located at the top of the piston close to the admission port, preventing the new mixture from mingling with the burned gases which are being forced out through the open exhaust port (E). The further upward movement of the piston closes admission port (A) with the exhaust port E still partly open. The next position of the piston closes all the ports, and compression takes place. During the later part of the upward stroke the inlet port (I) is opened by the lower edge of the piston, and a fresh supply of gas is drawn into the crank case, due to the partial vacuum created in it by the upward stroke of the piston.



Legend

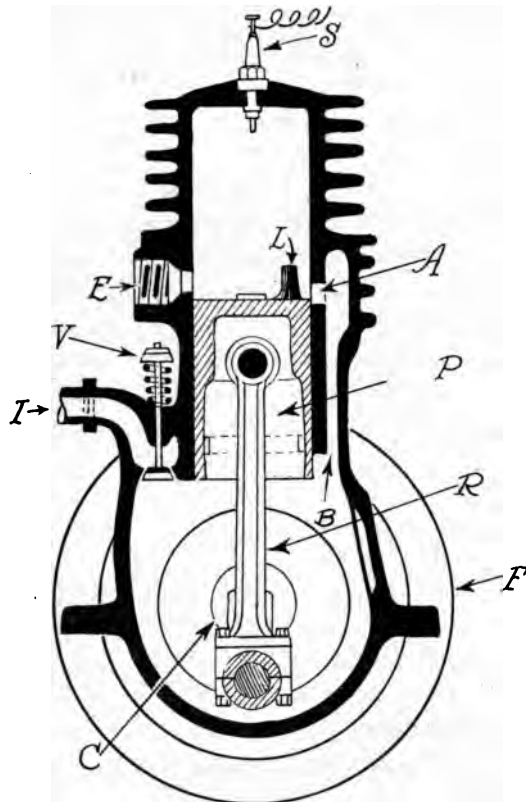
S-Spark Plug B-Bypass
L-Baffle Plate F-Flywheel
A-Admission Port C-Crank Shaft
P-Piston I-Inlet Port
R-Connecting Rod E-Exhaust Port

Fig.11.
The Two-Stroke Three Port
Engine

Stroke 2. Piston moving down. At the beginning of the downward stroke with ports A and E closed by the piston, ignition takes place, the explosion forcing the piston towards the crank case. This causes the partial compression of the fresh mixture contained in the crank case as soon as the inlet port (I) is closed by the lower edge of the piston. The further downward movement of the piston opens the exhaust port (E) relieving the pressure in the cylinder, and soon after this the piston uncovers the admission port, which allows the partially compressed gas from the crank case to enter the cylinder. The engine is then ready to begin a new cycle with the next upward movement of the piston.

Fig. 12 is a cross section of an air cooled vertical two-port two-cycle motor, also single acting, In this engine the automatic inlet valve (V) takes the place of the inlet port of the three-port type, admitting the fresh gas to the crank-case through inlet pipe I. In all other respects its action is the same as in the three port motor.

The two cycle motor is particularly well adapted for small motor boats due to its freedom from valve troubles and the more uniform power it delivers to the propeller. The four-cycle motor is better adapted for stationary power plants or for engines having a large HP. rating, on account of its higher efficiency and better regulation.



Legend

I~Inlet Pipe *A*~Admission Port
V~Inlet Valve *P*~Piston
E~Exhaust Port *B*~By pass
S~Spark Plug *R*~Connecting Rod
L~Baffle Plate *F*~Fly Wheel
C~Crank Shaft

Fig. 12
 The Two-Cycle Two-Port
 Engine.

THE DOUBLE ACTING ENGINE.

In large gas-engine installations where space is an important factor of economy, the engines are built double acting, i.e., with both ends of the cylinder being utilized as combustion chambers to develop mechanical power. This involves a radical change in the cylinder construction and in the arrangement of valves. The cylinder of a double acting engine is closed at both ends, the crank-end having an opening for the **piston-rod** which is rigidly connected to the piston in the same manner as in the steam engine. The piston rod fits in a bushing bolted to the cylinder end and made gas-tight by means of special packing. The crank-end of the piston rod terminates in a **cross-head**, moving in guides which regulate its reciprocating motion with the piston. The connecting rod is attached to the cross-head, its other end being connected to the crank shaft in the same manner as in the single acting engine.

In a four-cycle motor of a double acting type, both the admission and exhaust valves are duplicated at each end of the cylinder, each pair of similar valves being connected to the same inlet or exhaust pipe, as the case may be. In a two-cycle double acting motor the crank case is equipped with only one automatic inlet valve. The cylinder has two admission ports at each end, supplied from the crank case by a double by-pass. Each cylinder end is supplied with a separate

exhaust port located in the same relative position as in the single acting motor. One apparent advantage of the double-acting two-cycle motor, is the fact that it delivers a power impulse at every stroke of the piston. The additional equipment required for this motor is, however, a drawback and such construction is therefore employed only in large stationary gas-power plants.

THE CYLINDER.

The principle working parts of a single cylinder gas motor are shown in Fig. 13 which is a simplified drawing of a horizontal engine, the upper view (a) being a partial plan section through the crank shaft, and the lower view (b) is a longitudinal section taken through the center line of the cylinder. Referring to Fig. 13, (C) is the cylinder casting, shown solid for simplicity. Usually there is provision made for cooling it by water or air as shown in Figs. 10, 11 and 12. This casting is bolted to the crank-case (S) which may have any shape required for the particular installation of the motor. The **piston** (P) is shown in section with the **piston rings** (T) pressing against the cylinder walls. About two-thirds down in the piston there is a tapered hole drilled in it through which the wrist-pin (W) is driven, for attaching the **connecting rod** (R). The other end of R is fastened to the crank-pin (N) which is offset from the **crank shaft** (K) and is

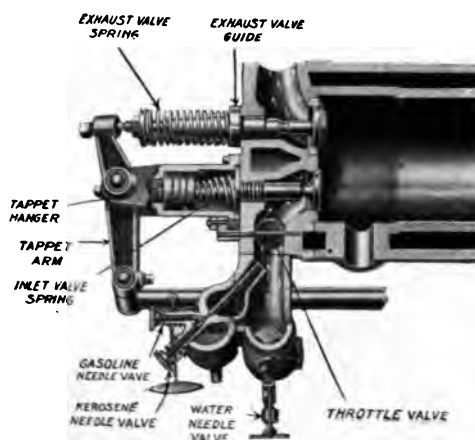


Fig. 14

Sectional through cylinder of a Horizontal Four Cycle Motor built
by the International Harvester Co.

counterbalanced by the weight (M). The **fly-wheel** (F) is keyed to the crank shaft close to one of the crank-shaft bearings (B).

Fig. 14 shows the interior of a cylinder of a horizontal engine built by the International Harvester Company, with the principal parts marked.

We will now take up the discussion of the principal parts of the single-cylinder engine in detail.

PORTS.

The communication between the engine cylinder and the gas supply system is made through the **admission port** or an opening made in the cylinder wall for that purpose. The **exhaust port** is a similar opening provided for the escape of the products of combustion from the cylinder to the atmosphere. In the two-cycle motor the ports are opened and closed by the motion of the piston. In the four-cycle motor the opening and closing of the ports is controlled by means of **valves**.

VALVES.

The admission valve is frequently made automatic, depending in its action upon the suction of air to the cylinder which lifts it from its seat against the action of the valve-spring. The size of valve opening depends upon the size of cylinder bore, the length of piston stroke, and the speed of the motor, since these three factors determine the quantity of gas used in the cylinder per minute.

The proper diameter for an automatic admission valve can be calculated from the following formula:

$$D = (B \times L \times N) \div 12,700 \quad (1.)$$

Where D is the diameter of admission opening in inches, B is the cylinder bore in inches, L is the length of stroke in inches, and N is the number of revolutions per minute.

For a mechanically controlled inlet valve the diameter of its opening should be:

$$D = (B \times L \times N) \div 15,000 \quad (2.)$$

Where the letters have the same meaning as above.

In motors running at very high speeds these valve diameters should be increased about 15%, in which case the formula for the diameter of opening becomes:

$$D = (B \times L \times N) \div 10,800 \quad (3.)$$

for atmospherically controlled valves, and

$$D = (B \times L \times N) \div 13,000 \quad (4.)$$

for mechanically controlled valves.

The values given in formulae 2 and 4 apply, with slight modifications, to the exhaust valves, which are always mechanically operated.

The amount of lift for the full opening of the valve depends upon the diameter of this opening and also upon the form of its seat. For a mushroom-shaped valve having a flat seat, the lift should be about one-quarter of the diameter of opening. For a valve having a bevel seat, the lift should be about three-eighths of the diameter.

These relations can be expressed by the formula :

$$L = 0.25D \quad (5.)$$

where L is the lift in inches, and D is the diameter of opening with a flat seat,

$$\text{and } L = 0.35D \quad (6.)$$

for a valve with a bevel seat.

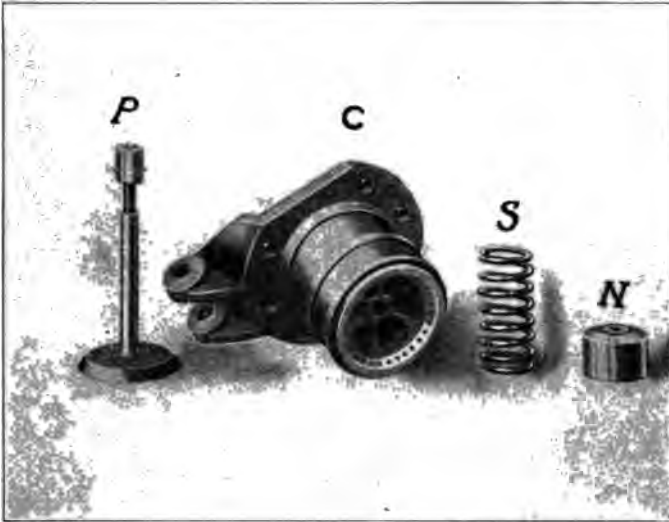


Fig. 15

Construction of Inlet Valve and Cage Used on Du Bois Single Cylinder Throttling Engine. Du Bois Iron Wks.

Fig. 15 illustrates the detail parts of an admission valve taken from a single cylinder engine made by Du Bois Iron Works, showing the valve spindle (P) the valve cage (C) which houses the

valve, the spring S, and nut N which secures the spring in its place around the spindle.

PISTON

One of the principal requirements of the piston is to have it fit tight to the bore of the cylinder so as not to admit any gases from the combustion chamber to the crank case, or to the other end in case of double-acting engines. This fit must not be so close, however, as to cause undue frictional



Fig. 16

Parts of the Piston made by the International Harvester Co.

resistance to its motion. These requirements can be fulfilled by having both the cylinder bore and the outside surface of the piston absolutely true and finished smooth; also by keeping these surfaces clean and well lubricated; and, finally, by providing special metal bands or "**Piston rings**" fitting loosely around the piston, as shown in Fig. 13, marked (T). These rings are made of special iron having high elasticity, with their outside diameters slightly larger than the cylinder bore. They are split at one point, and a slot is cut out making

their outside diameters smaller than the bore of the cylinder when they are tightly compressed. This makes them act like springs when they are forced in the grooves provided for them around the piston. Fig. 16 shows the parts of a piston taken from a gas motor manufactured by the International Harvester Co., having four rings with four corresponding grooves cut around the piston.

The piston is usually made hollow, with a tapered hole drilled through it for the wrist pin, the



Fig. 17

Marine Type Connecting Rod. The Heer Engine Co.

thickness of the metal being governed by the required strength, and limited by weight, especially for aviation motors.

CONNECTING ROD.

The detail parts of a connecting rod of a Heer Marine Engine are shown in Fig. 17, the larger opening at one end fitting on the crank shaft, and the smaller opening at the other end made to fit the wrist pin. These holes are made large enough to allow space for bronze bushings which are re-

quired between the moving pins and the rod, to eliminate friction. These bushings can be tightened by bolts as shown in Fig. 17.

WRIST PIN.

This pin is held in its position in the tapered hole of the piston by a small set-screw. Care should be taken to have this connection frequently inspected to prevent the connecting rod from getting loose.

CRANK CASE.

The crank case is made of a light metal, especially in aviation motors, and it is bolted to the cylinder casting, this connection being made gas-tight by means of special gaskets to prevent the escape of fuel. The crank case should have an opening which is normally closed by bolts to provide for facility of inspection and repairs of the crank shaft and other mechanism enclosed by it.

CRANK SHAFT.

In the single cylinder motor the crank shaft consists of one bent portion forming the crank-pin, to which the connecting rod is attached. (See (b) in Fig. 13.) Its ends rest in bronze or brass bearing surfaces to eliminate friction.

Usually the center line of the crank shaft is directly in line with the center line of the cylinder as shown in Figs. 10, 11, 12 and 13. With this

arrangement the connecting rod exerts a large side pressure or thrust against the walls of the cylinder on account of the angle made by the connecting rod and the center line of the cylinder during some parts of the cycle. To avoid this, the connecting rod is made as long as possible, which makes this angle, and therefore the side pressure much smaller. But this is objectionable, especially for aviation motors, where every ounce of metal must be saved. A better way to eliminate this trouble is to **offset** the crank shaft, or to move it to one side of the center line of the cylinder. The effect of this offsetting is to decrease the angle between the connecting rod and the cylinder, which diminishes the side pressure on the cylinder wall. In case the cylinder is relatively moved to one side of the crank shaft in the direction of its rotation, this will increase the length of the allowable piston stroke which consequently increases the efficiency and power output of the motor.

In a double-acting motor we have the additional parts required for the utilization of both ends of the cylinder, which are as follows:

THE PISTON ROD.

This is usually a round rod made of strong metal, rigidly connected to the crank end of the piston and ending in a cross-head. The size of the rod may be computed by the formula

$$D = 0.0144 \times B \times \sqrt{P} \quad (7)$$

where D is the required diameter of the piston rod, B is the cylinder bore, both in inches, and $\sqrt{P}$ is the square root of the maximum unbalanced pressure in lbs. per square inch.

CROSS HEAD.

Similar in shape and in its functions, to the same part of a steam engine. The opening in the cross head is made large enough to enclose the cross head pin and a split bushing which can be tightened or **keyed** by means of bolts.

ENGINE BEARINGS.

The various types of engine bearings used in gas motors may be classified as follows:

I. Plain Bearings.

- (1) Hard.
 - (a) Brasses.
 - (b) Bronzes.
 - (c) Special hard alloys.
- (2) Soft.
 - (a) Babbitt metal.
 - (b) Anti-friction metal.
 - (c) White metal.

II. Ball Bearings.

- 1. Thrust bearings.
- 2. Cone “
- 3. Annular “

The use of each of these types will be illus-

trated in the later chapters dealing with practical applications of the gas motor.

KEYS.

These are used in fastening gears and cams to their respective shafts and they should be driven in place under pressure. In recent types of gas motors most of the keys are eliminated by building the parts solid on their shafts, thus rendering them absolutely reliable.

FLY-WHEEL.

The function of the fly-wheel is to provide enough momentum to the rotating shaft to continue its motion during the idle parts of the cycle. Since momentum is a physical quality depending upon the mass and velocity of the moving body, the weight of the fly-wheel and its proper diameter must be adapted to the requirements of each particular motor. The proper weight of the rim of a fly-wheel can be computed from the following formula, the weight of the web, spokes and hub being in this case negligible.

$$W = \frac{P \times A \times L \times N}{2560 \times D} \quad (8)$$

where W is the weight of the rim in lbs., P is the mean pressure of the compression, A is the cross-sectional area of the piston in square inches, L is the length of stroke in inches, N is the number

of revolutions per minute, and D is the external diameter of the wheel in inches.

MUFFLER.

This is a special device used for directing the gases coming from the engine exhaust through a number of small partitions, which gives these gases a chance to expand and thus to deaden the noise of their exit to the atmosphere. The use of a muffler tends to create a back-pressure in the cylinder during exhaust, especially in case the muffler is clogged up with dirt or deposits of soot from the gases, thereby causing a loss in the power output of the motor. Most gas motors are provided with a special by-pass valve located near the muffler which can be opened by the operator in order to allow the gases to escape directly to the atmosphere. This develops more power in the motor and it is used in automobiles for picking up the speed rapidly after a slow down or in climbing steep grades.

COMPRESSION LEAKS.

Among the greatest troubles encountered in operating gas motors are the many forms of gas leaks from various parts of the cylinder known as **compression leaks**, which are mostly due to the following **causes**: Leaking valves; worn out gas-leaks or packing at the crank case, at the cylinder head, or at the piston rod bushing of double acting

motors; leaks through the cylinder openings for ignition; worn cylinder bore; worn, or stuck piston rings; cracks in the cylinder casting; cracks in the piston; piston ring slots all getting in line; soft piston rings; blow-holes in the cylinder and piston castings, etc.

TESTS.

Compression leaks are usually made evident by peculiar blowing or barking noises occurring in time with the speed of the engine. In severe cases this is supplemented by the appearance of puffs of smoke at each explosion of the engine. A practical way of locating the leak is to hold the hand near the part where the noise seems to come from. A better way is to throw some soapy water on the joint which is suspected, and the leak will be indicated by small bubbles caused by the escaping gas.

REMEDIES.

In some cases the parts affected can be made gas-tight by oiling them or tightening up the connections. In very severe cases the faulty part has to be renewed. Worn valves can be made tight by regrinding them in case they are not greatly damaged. It is very important to stop compression leaks as soon as they are discovered, otherwise the trouble may spread rapidly until the

parts so affected are ruined beyond any possibility of repair.

QUESTIONS ON CHAPTER III.

1. What are the advantages and disadvantages of the four-cycle motor?

2. What are the advantages and disadvantages of the two-cycle motor?

3. In what cases is the use of double acting engines justified? Give reasons.

4. What are the principal parts of the single cylinder engine?

5. A Vertical Four-cycle engine has a bore of $4\frac{1}{2}$ inches, a stroke of 5 inches and a normal speed of 1200 R. P. M. Find the proper opening and lift for the admission valve, which is operated by suction, and has a bevel seat.

6. Find the proper dimensions for the exhaust valve of the engine specified in question 5.

7. What are the advantages gained by offsetting the cylinder?

8. A double acting gas engine has a bore of 12 inches and a maximum unbalanced pressure of 360 lbs. per square inch. Find the required size of the piston rod.

9. Find the proper weight of rim of an 18 inch fly-wheel in an engine having a compression of 80 lbs. per square inch, a cylinder bore of 6 inches, length of stroke 6 inches and running at 1080 revolutions per minute.

10. What are the causes for power lost in using a muffler?

11. What are the principal causes of compression leaks?

12. How can a compression leak be quickly detected?

ANSWERS TO QUESTIONS ON CHAPTER II.

1. The products of combustion of producer gas are mostly carbon dioxide, water vapor and nitrogen, also a small amount of carbon monoxide due to incomplete combustion.

2. Gasoline having a specific gravity of 75° B. weighs about 5.68 lbs per gallon. To fill a 30 gallon tank we need:

$$5.68 \times 30 = 170.4 \text{ lbs. of gasoline.}$$

3. Assuming that we have a light gasoline with a density of 81° B., its specific gravity compared with water is 0.6655 (see Table 2). The pressure of one foot of water is equal to 0.433 lbs. per square inch. The pressure of flow due to ten inches of gasoline is equal to

$$0.433 \times (10/12) \times 0.6655 = 0.239 \text{ lbs. per square inch.}$$

4. The auxiliary air pump is used in the pressure supply system for starting and in cases of temporary failure of pressure from the exhaust.

5. The carbureter performs the double duty of vaporizing the fuel and mixing it with the proper amount of air.

6. In a float-feed type of carbureter the supply of gasoline is regulated by an automatic spindle valve which is raised or lowered with the level of liquid in the float-chamber.

7. The speed of the motor controls the number of suction strokes per minute. The gasoline supply and the quantity of air admitted to the carbureter both depend upon the duration and frequency of these suction periods. Therefore with greater speed the carbureter becomes more active.

8. The multiple-spray carbureter has the advantage of varying its supply of gasoline according to the demands of the motor.

9. The automatic carbureter having a spring-controlled supply valve does away with the splashing and jarring troubles inherent in all float feed carbureters. It is not reliable on high speed motors on account of the excessive inertia of its valves.

10. Gasoline supply may fail due to empty or closed tank, failure in flow system or trouble in carbureter.

11. Excess in gasoline supply reduces the power output of the motor and causes a layer of carbon deposit in the cylinder and valves.

12. Dirt and water could be kept out of the gas supply system by straining the gasoline and overhauling all the parts frequently.

CHAPTER IV.

THE MULTIPLE CYLINDER ENGINE.

In order to overcome the difficulties of unbalanced power, which is a common fault with all single cylinder gas engines, the present types of gas motor are usually made up of several cylinders all connected to the same crank shaft and arranged in such a manner as to deliver their respective power impulses to the shaft at regular intervals of time, depending upon the type and speed of the motor.

This results in a more even and continuous rotary moment or **torque** which acts upon the crank shaft, doing away with the sudden jars and jerks due to unbalanced power and causing less noise and strain in the working parts of the motor.

A gas engine having more than one cylinder is termed a **multiple cylinder engine**, and with four cylinders of the four-cycle single acting type it will deliver two power impulses for every revolution of the shaft. Using four cylinders of the two-cycle single acting type the motor will have four power strokes per revolution.

The number of power impulses per revolution of the crank shaft can be computed as follows:

For a Single acting Four-cycle motor

$$N = \frac{C}{2}, \text{ where } N \text{ is the number of impulses per}$$

revolution and C is the number of cylinders.

For a single acting two-cycle motor, $N = C$, the letters having the same meaning as above.

For a double acting Four-cycle motor we have again:

$$N = C$$

Finally, with a double acting two-cycle motor,
 $N = 2 C$.

Another advantage of the multiple cylinder engine is its capacity for greater power output without increasing the size of the working parts of the cylinders. This involves a saving in expensive equipment required for the larger cylinders and it increases the practical limiting H.P. capacity of the gas motor. Up to the year 1917, the maximum output of a single cylinder gas engine has reached about 800 H.P., and with multiple cylinder engines the maximum output of the gas motor has gone up to about 2200 H.P.

ARRANGEMENT OF CYLINDERS.

The multiple cylinder engine can be classified according to the number of its cylinders, thus: **Two-cylinder, three-cylinder, four-cylinder, etc.**

In relation to the position of the cylinders in space they may be classified as **horizontal** and

vertical. With the recent development of special gas motors used for propelling airplanes and dirigible balloons, and even submarines, this division into horizontal and vertical types is beginning to lose its significance since in these cases the motor may assume any position in space. In all cases, in a horizontal engine the cylinders are parallel to the plane of their support, while in a

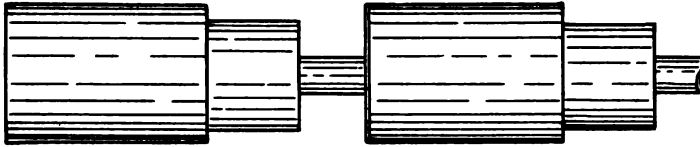


*Fig. 18.
Horizontal Two Cylinder Motor
With Tandem Cylinders*

vertical engine the cylinders are perpendicular to the base.

In reference to the relative position of the cylinders to the crank shaft the multiple cylinder engine can be still further subdivided into various types, as outlined below.

Fig. 18 shows an arrangement of horizontal cylinders in line, one ahead of the other. This is known as the **Tandem** type, and is used mostly for large stationary engines.

Another common method of compounding large horizontal stationary gas motors is to place one

cylinder alongside of the other and connect them to the same crank shaft. This is known as the **Duplex** type, as shown in Fig. 19.

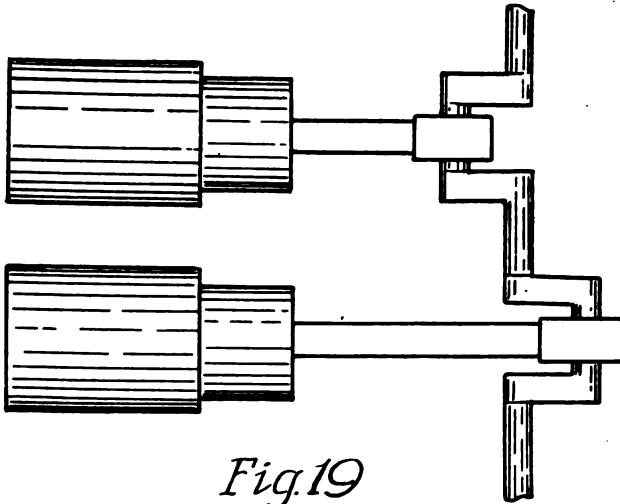


Fig. 19
Horizontal Duplex Motor

A very simple arrangement of any even number of horizontal cylinders, known as the “**horizontal-opposed**” type, is illustrated in Fig. 20. It is called the “opposed” engine on account of the cylinders being placed opposite one another, the two rows being staggered or offset, as shown in Figs. 20 and 25. This type of motor is frequently used for small automobiles equipped with two cylinders.

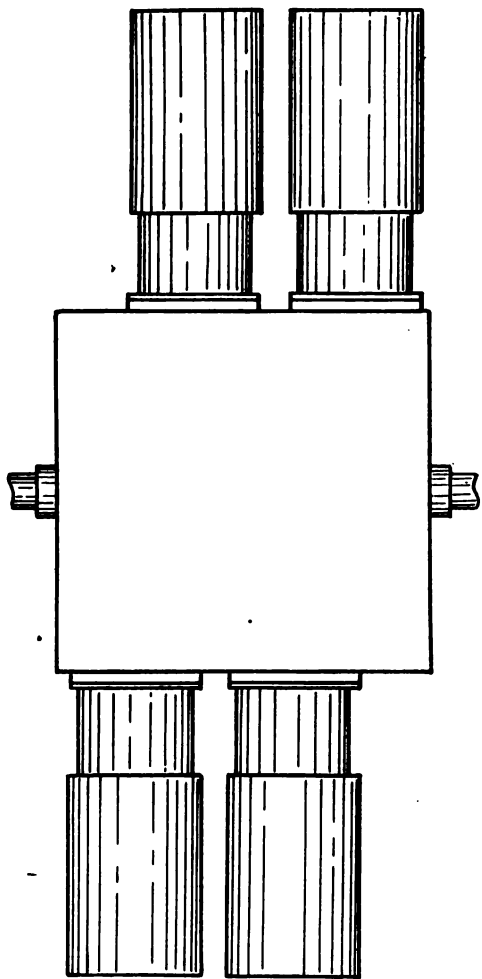


*Fig. 20.
Four-Cylinder Horizontal-Opposed Type Motor.*

The same type motor, but having from four to sixteen cylinders is at present used extensively in several makes of airplanes in this country and



Fig. 21
Four-Cylinder Vertical Motor

abroad, especially in France, where the horizontal-opposed engine at first met with very little favor. The details of this engine, as applied to motor vehicles, are shown in Fig. 25, which will be described later.

Fig. 21 is a simplified diagram of the most common type of gas-engine, namely, the **Four-cylinder Vertical** motor. It is used in many stationary power plants, in motor vehicles, boats, flying machines, agricultural machines, etc. The vertical four-cylinder motor is so universally popular on account of its economy in space made possible by this compact arrangement, and also on account of the fact that it delivers at least two power impulses for every revolution of the shaft.

Fig. 22 illustrates a very common distribution of cylinders used in modern airplane motors, known as the **V-type** and adapted for any even number of cylinders, which may be inclined to one another at any angle between 90° and 30° . This arrangement has the advantage of symmetry which is important for securing lateral stability in any flying machine.

Other varieties of gas motors recently developed for aviation are the various types of **fan-shaped** engines using from three to seven cylinders in each fan (see Fig. 23); also the **star** or **radial** types used for both the automobile and the airoplane (see Fig. 24). The latter, or the radial type motor may have a stationary crank shaft and revolving cylinders, as in the Adams Five-cylinder horizontal engine used for driving automobiles, and in the Gnome revolving-cylinder motor used for aviation.

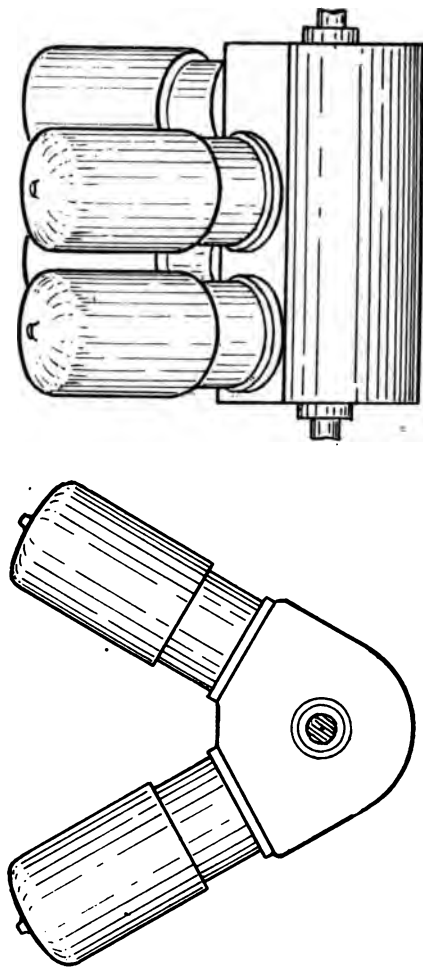


*Fig. 22.
Four-Cylinder V-Type Motor*

Referring to Fig. 24, which is a simplified diagram of the Adams motor, the crank shaft S is stationary, and it has a single throw which is offset

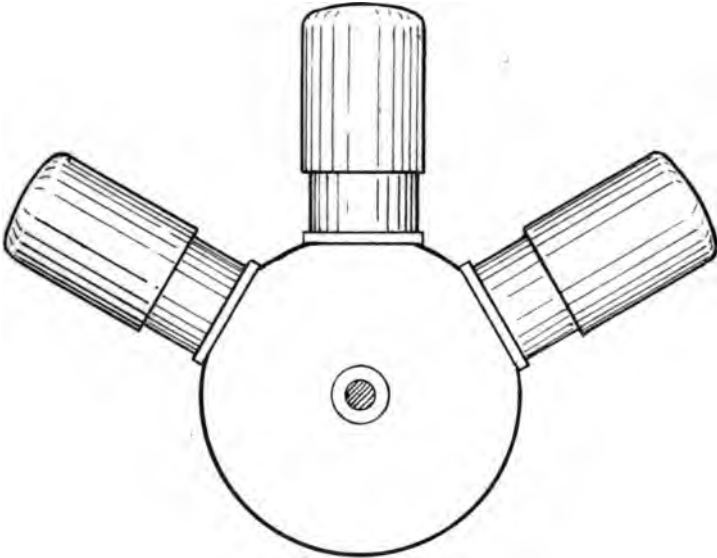


Fig. 23
Three-Cylinder Fan Type Motor

from the common crank pin of the five connecting rods. The cylinders are all rigidly joined together. They are here shown revolving in the direction of the arrow. The piston in cylinder A is moving toward the crank pin, thus urging the

cylinders in the proper direction. Each cylinder, as it passes the position occupied by A reaches a similar part of its cycle.

VALVE MECHANISM.

The revolving-cylinder motor has mechanically controlled inlet and exhaust valves, all of them

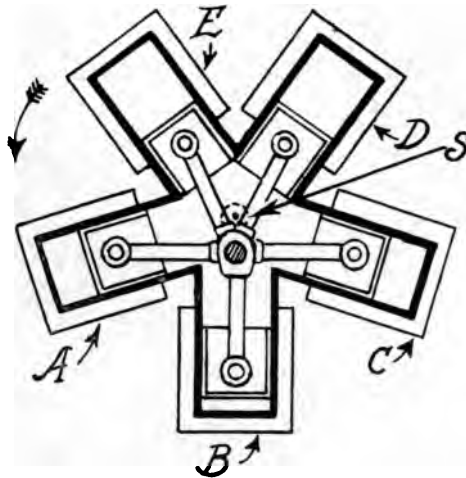


*Fig. 24.~Five-Cylinder Star-Type
or Radial Motor.*

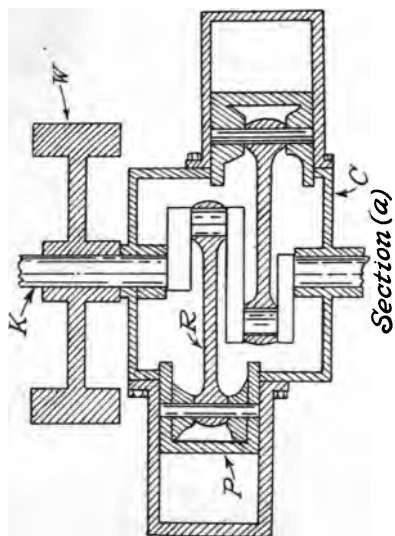
being operated by a single cam, which is stationary. These valves are opened by means of rocker arms and rods running parallel to the axes of their

respective cylinders. The stationary cam controlling the valves has a movable lower portion which can be adjusted to regulate the period of opening of the intake valves. This affects the amount of compression in the cylinders and is used to regulate the power output and the speed of the motor.

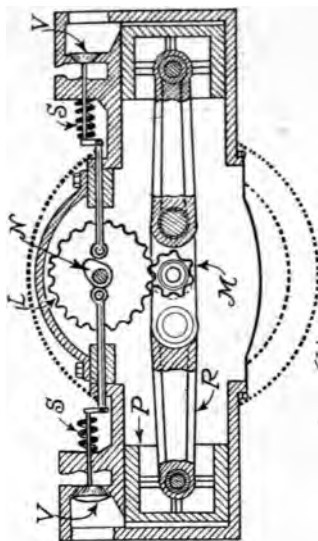
In general, the arrangement of cylinders in the multiple-cylinder gas motor requires special methods for controlling the opening and closing of the valves in each particular type of motor.

CAM SHAFT.

Since the time of operating the valves in the various cylinders of the motor depends upon the speed of the engine, the cam shaft which carries all the cams controlling these valves is always geared to the crank shaft in the ratio of one to two for four-cycle cylinders. In some motors the cam shaft also carries the **timing** devices for ignition. Usually this shaft is parallel to the crank shaft and is geared to it by means of spur gears as shown in Fig. 25 (see section b). In large stationary gas engines arranged in tandem, as shown in Fig. 18, the cam shaft runs parallel to the bores of the cylinders, or at right angles to the crank shaft. This type of cam shaft is usually known as the **Lay Shaft**, and it is geared to the crank shaft by means of either bevel or spiral gears.



Section (a)



Section (b)

Fig. 25
Two-Cylinder Horizontal-Opposed Engine.

The cam shaft has attached to it as many cams as there are cylinders in the motor in case the inlet valves are automatic, or twice as many cams as there are cylinders, for motors having mechanically controlled inlet valves. These cams are arranged at different angles so as to operate each individual valve at the proper position of the crank shaft, and in most recent types of motors the cams are made solid with the shaft in order to avoid the danger of any of them getting loose and keeping their corresponding valves closed, which would leave the affected cylinders idle.

TWO CYLINDER HORIZONTAL ENGINE.

The details of the two cylinder horizontal-opposed type engine are shown in a simplified manner in Fig. 25. Section (a) is taken horizontally through the center line of cylinders, and section (b) is taken vertically, showing the valve mechanism. The cranks on the crank-shaft (K) are offset in opposite directions, or at 180 degrees, so that as the shaft goes through one half of a revolution, the pistons (P) are both either brought together or moved apart by the action of the connecting rods (R), as shown in section (a). The valves are arranged in such a manner that when the two pistons are brought together, one is at the end of its power stroke, and the other is at the end of admission; when the pistons are at their

farthest distance apart, one is at the end of exhaust and the other is at the end of compression. In this manner we obtain one power stroke for every revolution of the crank shaft. The exhaust valves (V) are operated alternately from the same cam N by means of gears L and M and they are held on their seats by the valve spring (S) (see Section (b)).

This type of engine is well balanced both in space and in its power output, and therefore has the advantage of smoothness of operation.

TWO CYLINDER VERTICAL ENGINE.

In the two-cylinder vertical engine the parts of the cylinders are merely a duplication of the single cylinder engine. The crank shaft has the required two cranks which may be either both turned in the same direction, or set at an angle of 180 degrees, in the same manner as in the opposed-horizontal engine. With both cranks turned in the same direction, both pistons move either up or down at each half revolution of the shaft. This results in one power impulse delivered to the shaft at the end of every revolution, giving a well-balanced, smooth operation. In case the two cranks are set opposite to one another, then each half revolution of the shaft moves one piston up and the other down. As a result of this we get two power impulses delivered to the shaft during one revolution, and none at all during the next succeeding

revolution. This causes a greater amount of noise and vibration in the working parts of the motor due to the imperfectly balanced power strokes, but it increases the power output of the motor by concentrating the force of the two explosions during the same revolution of the shaft. In this respect the method of setting the cranks at 180 degrees has an important advantage, although it does not give very smooth operation.

FOUR-CYLINDER VERTICAL ENGINE.

A common type of a four-cylinder engine is shown in Fig. 26, in which the cylinders are numbered from left to right in their proper order. Cylinder No. 1 is shown in section taken through the center line of the piston, cylinder No. 2 is a section through the center of the valves, cylinder No. 3 shows the valves partly covered, with only the valve springs visible, and cylinder No. 4 is shown as it appears in elevation. The crank offset at the left end of the crank shaft (K) is in its upper position, which indicates that the piston in cylinder 1 is at the end of either compression or exhaust. In cylinder 2 both the inlet valve (V) and exhaust valve (E) are closed. They are both mechanically operated by the cam shaft M actuating the valve-lifting rods (L) against the tension of the valve-springs (S) in the same manner as in the single-cylinder and two-cylinder engines. In order to prevent vibration in the motor caused by

a regular succession of power impulses from one end of the crank shaft to the other, the crank and cam shafts are built to provide for a break in the successive explosion strokes of the four cylinders. The usual order of firing in the cylinders is either 1-3-4-2, or 1-4-3-2.

The events taking place in the cylinders during a complete cycle of the motor can be clearly understood by studying the following table, which is arranged assuming an order of firing of 1-3-4-2 for a four-cycle type of motor. (See page 98.)

The successive events in each cylinder are indicated in the vertical columns marked with the cylinder numbers. The events taking place at the same time in the various cylinders are indicated in the horizontal columns marked with the position of the crank shaft. The power stroke occurs in cylinder No. 1 during the first half of the revolution, then in No. 3 during the end of the first revolution, in No. 4 during the first half of the second revolution and in No. 2 at the end of the second revolution, which completes the cycle of the motor. The other events occur in the same order, while in each individual cylinder the order of events is: suction, compression, power and exhaust.

Some vertical four and six cylinder engines are built in pairs, as in the Buick motor used for automobiles. The action is exactly the same as in the

POSITION OF CRANK SHAFT	CYLINDER No. 1		CYLINDER No. 2		CYLINDER No. 3		CYLINDER No. 4	
	PISTON	EVENT	PISTON	EVENT	PISTON	EVENT	PISTON	EVENT
First Half Revolution	Going Down	POWER	Up	Exhaust	Up	Com- pres- sion	Down	Suction
Second Half Revolution	Going Up	Exhaust	Down	Suction	Down	POWER	Up	Com- pres- sion
Third Half Revolution	Going Down	Suction	Up	Com- pres- sion	Up	Exhaust	Down	POWER
Fourth Half Revolution	Going Up	Com- pres- sion	Down	POWER	Down	Suction	Up	Exhaust

Table of Four Cylinder Action

engine having separate cylinders, but the details of valve mechanism are changed to fit this arrangement.

SIX AND EIGHT CYLINDER ENGINES.

Many recent types of automobile motors are built with six and eight cylinder engines. These motors have the advantage of delivering a more balanced form of power and a greater total power output. But it is questionable whether the added expense for the extra cylinders above six is justified in this case in view of the many practical and legal speed limitations of all motor vehicles and the greater chance for some of the duplicate parts of the motor to get out of order, which may involve considerable loss of time and money for repairs.

For use in aviation, however, the large number of cylinders is fully justified, since, in the first place, the peculiar requirements of space do not allow the use of fewer and larger sized cylinders. Besides delivering a more uniform torque to the propeller, which is very important for aviation, the larger number of cylinders insures greater reliability of service and develops higher propeller velocities. This tends to increase both the speed of the machine and its lifting capacity, as is more fully explained in Chapters XI and XII dealing with aviation motors.

ADVANTAGES AND LIMITATIONS OF MULTIPLE CYLINDER ENGINES.

To summarize, the principal advantages gained by the use of more than one cylinder in a gas motor are as follows:

- (1) More balanced power.
- (2) Greater possible power output.
- (3) Greater reliability of service.
- (4) Better arrangement for limited space.
- (5) Greater speeds possible with small-sized cylinders.
- (6) Cheaper equipment which can be easily duplicated.

The practical number of cylinders is, however, limited in many cases by the special requirements of speed and power output and by the fact that with the greater number of elements the losses are multiplied in the same ratio, lowering the final efficiency of the motor. This is the reason why for stationary power plants the gas motor should be made up of a few very large cylinders, while for service where speed and reliability are most important, the motor should consist of a large number of small cylinders. The special requirements in each case must govern the selection of the gas motor best suited for the purpose.

CYLINDER TROUBLES.

The majority of cylinder troubles originate outside of the cylinders themselves:—in the ignition system, the valve mechanism, also the cooling, gas mixing and lubricating system. It is evident that faulty ignition or a total failure to fire the charge, will lower the efficiency of the motor. This also damages the parts of the cylinder by straining the metal in case the spark is too far advanced, or by overheating the cylinder walls in case the spark is retarded.

Any improper valve operation tends to reduce the power output of the motor by either partially or completely cutting down the power developed in the cylinders so affected. Any serious failure in the cooling supply system tends to overheat the cylinder walls, causing cracks in the cylinder and piston, as well as compression leaks in all the parts of the cylinder and valves; also **preignition** of the charge and **back firing**, or an explosion during the early part of the cycle tending to rotate the shaft in the opposite direction.

The cylinder troubles due to faulty oil supply consist mostly of overheating; compression leaks; undue friction at the piston, and the general rapid wearing out of the parts of the motor lacking proper lubrication.

A mixture that is too rich in fuel will cause a deposit of carbon in the cylinder, resulting in preignition and back firing.

A weak mixture retards the rate of combustion, causing overheating and also back-firing.

Among other common causes of cylinder troubles may be mentioned: leaky valves; broken parts of valves; broken piston rings; worn out packing, etc.

REMEDIES.

Most of the cylinder troubles due to defects in the ignition system can be avoided by keeping the connections clean and well protected from moisture.

The valve mechanism must be frequently inspected and valves should be reground as soon as any leak through them is detected.

Great care must be taken to have a sufficient supply of water in the cooling system before the motor is started, as any addition of water to the jacket with a hot cylinder will cause overstrain and cracking of the cylinder walls.

All the oil and grease cups should be carefully inspected and filled before the engine is started, and none of the motor parts should be allowed to run for any length of time without receiving their proper amount of lubrication. The supply of oil to the cylinder should not be excessive, as this will cause preignition and back firing.

In general, all the parts of the motor must receive their due share of attention, especially before starting on a long trip, or after the motor has been idle for a considerable period of time.

QUESTIONS ON CHAPTER IV.

1. What is the usual arrangement of cylinders for stationary gas engines?
2. What types of motors are used for aviation?
3. What are the advantages of the "horizontal-opposed" type of gas motor?
4. How are the cycle events of the two-cylinder vertical engine affected by the construction of the crank shaft?
5. What are the general features of construction of a cam shaft for a vertical four-cylinder engine using mechanically controlled valves, and firing the cylinders in the order 1-3-4-2?
6. Find the number of power impulses per revolution delivered to the shaft of a 16-cylinder motor using two-cycle, single-acting cylinders.
7. What are the advantages of the revolving-cylinder type of motor?
8. Name the advantages and limitations of the multiple cylinder motor.
9. What is the rated brake H.P. of an automobile engine equipped with eight cylinders having a bore of 5 inches each?
10. Enumerate the most common cylinder troubles due to a failure of the cooling system.
11. What are the causes of back-firing?
12. What precautions must be taken in starting the motor in order to avoid break downs due to cylinder troubles?

ANSWERS TO QUESTIONS ON CHAPTER III.

1. The four-cycle motor has better regulation and is more economical in fuel, but it has the disadvantage of unbalanced power and complicated equipment.

2. The two-cycle motor has twice as many power strokes per revolution as the four-cycle machine, but it operates at a lower efficiency.

3. The double-acting engine should be used in large stationary installations on account of the economy in space, less strain in the material, and the greater efficiency made possible by utilizing both ends of the cylinder for developing mechanical power.

4. The principal parts of the single-cylinder engine are: The cylinder; the piston; ports; valves and valve mechanism; crank shaft; cam shaft; connecting rod; wrist pin; crank case and engine bearings. In the double-acting engine we also have the piston-rod, cross-head and guides.

5. Using formula (1) Chapter III, the valve opening must be:

$D = (4.5 \times 5 \times 1200) \div 12700 = 2.1$ inches or about $2\frac{1}{8}$ inches in diameter. The lift is found by using formula (6), as follows:

$L = 0.35 \times 2.1 = 0.735$ inches, or practically, three-quarters of an inch.

The diameter of the exhaust valve is:

$D = (4.5 \times 5 \times 1200) \div 15000 = 1.8$ inches or about $1\frac{7}{8}$ inches. The lift is equal to $1.8 \times$

MULTIPLE CYLINDER ENGINE 105

$0.35 = 0.63$ inches, or practically about $\frac{5}{8}$ of an inch.

7. By offsetting the cylinder, the side pressure on the cylinder walls is diminished, and the efficiency of the motor is increased.

8. Using formula (7), Chapter III, the diameter of the piston required for this engine is as follows:

$D = 0.0144 \times 12 \times \sqrt{360} = 3.2$ inches, or about $3\frac{1}{4}$ inches.

9. The area of a six inch bore is about 28.3 square inches. Using formula (8), Chapter III, the required weight of the fly-wheel rim is:

$$\frac{80 \times 28.3 \times 6 \times 1080}{2560 \times 18} = 318.4 \text{ lbs.}$$

10. The use of a muffler obstructs the free passage of the products of combustion into the atmosphere and causes a back-pressure which reduces the power output of the motor.

11. The main causes of compression leaks are: overheating, poor lubrication, worn out parts and loose connections.

12. A compression leak can be quickly located by throwing some soapy water on the suspected joint, and noting the place where the gas-bubbles appear.

CHAPTER V

THE IGNITION SYSTEM.

The development of mechanical power in a gas motor from the heat energy contained in the mixture of gas and air requires the raising of its temperature to the point of **ignition** or burning, at the instant of maximum compression. The effect of igniting the compressed charge is to start the process of combustion of a very small portion of the mixture, after which the action spreads rapidly through the whole mass, causing an explosion which generates the mechanical power in the cylinder. The temperature of ignition varies with the character of the fuel, the amount of its compression and its initial temperature.

The process of ignition may be accomplished by compressing the gas to a point at which the heat developed by compression will be sufficient to fire the charge. This principle is partly made use of in some types of gas motors such as the Diesel engine and the Antoinette motor used for aviation. In these motors the air is admitted directly to the cylinders and compressed to about 500 lbs. per square inch, after which the fuel is injected. But in most of these motors an additional method of igniting the mixture is provided in order to over-

come the difficulty of correctly timing the explosions caused by compression.

Another method of firing the charge is by direct heating caused by a heated metal ball or a hot tube placed in the combustion chamber, the heat being supplied to the metal from an outside source. This system was very common in the early stages of gas motor development, but it has recently been almost entirely superseded by the modern electrical system of ignition. The principal disadvantages of the hot-metal ignition, in spite of its simplicity, are: the cost of fuel required to heat the metal; the difficulty of correct adjustment and firing, and the rapid deterioration of the equipment caused by the heat.

The various electrical ignition systems depend in their operation upon the heat generated in an air gap through which an electric current is forced in opposition to the resistance of the air. This heat is developed rapidly and it is accompanied by a peculiar sharp noise and bright **sparks** which are of the same nature as the thunder and lightning, only on a much smaller scale.

REQUIREMENTS OF THE IGNITION SPARK.

In order to obtain a spark hot enough for ignition, we must have the proper equipment for generating the required amount of electrical power in a form best suited for the purpose. This must also include some device for firing the ignition so that the spark occurs just at the proper point of

the cycle, depending upon the requirements of speed and power output. But before we can clearly understand the operation of the various parts of the ignition equipment, we must first get somewhat familiar with the methods of generating and measuring electrical power.

The most common method of generating electricity is by rubbing together two unlike substances, such as glass with silk or rubber with fur, etc. This creates what is known as an **"electric charge"** in each substance, giving them the quality of attracting light bodies and even causing small sparks to jump from them to any object placed in their vicinity.

This form of electricity is stationary or **static**, which means that the electric charge thus generated can not be made continuous or to flow along and definite path, and it can, therefore, not be utilized for delivering power.

The strength with which a charged body can attract another object depends upon the degree of its electrification, or the **electrical pressure** created by the static charge. This corresponds to the **pressure head** of a mass of water, or to the temperature of a heated body, and it does not indicate the quantity of electricity contained in the charged body. The practical unit of electrical pressure is the **volt**, and the amount of pressure between the terminal points of any electrical device is termed its **voltage**.

The principle of generating a static pressure of electricity between two bodies is utilized in the construction of the **condenser**, which is a device used for retarding the action of sparking across a small gap to which it is connected, by inducing an electric charge between thin metal layers, separated by glass or mica insulation.

The movable form of electricity capable of flowing in a definite direction is called an **electric current**, which requires for its operation a closed path, or a **circuit**. The medium through which an electric current can pass is called a **conductor**, and any substance that prevents the passage of an electric current is called an **insulator**. The quantity, or strength of any electric current is measured in **amperes**, and it depends upon the electrical pressure or voltage of the circuit, and upon the amount of resistance to the flow offered by the conductors contained in the circuit.

The amount of resistance developed by any conductor depends upon the quality of the conducting material, its length, and its size, or the area of its cross section in case of a wire. The resistance of any wire or cable can be computed by the formula:

$$R = \frac{l \times K}{A} \dots\dots\dots (1) \dots$$

where R is the resistance measured in **Ohms**, l is the length in feet, A is the cross-sectional area of

the conductor in square inches, and K is a special number called **specific resistance**, depending upon the material.

A circuit in which the current flows always in the same direction is said to have a **direct-current**, and in case the direction of flow is periodically reversed, we have an **alternating current**. The relation between the voltage, current and resistance of a direct-current circuit is known as **Ohm's Laws** and it can be expressed as follows:

$$C = \frac{V}{R} \dots\dots\dots (2)$$

where C is the current in amperes, V is the electrical pressure in volts and R is the total resistance in Ohms. The same relation can be written in the following way:

$$V = C \times R \dots\dots\dots (3)$$

or the voltage in any direct current circuit is equal to the product of the current, times the total resistance.

The electric current can be utilized in delivering electrical power to any part of the circuit to which may be connected any device using power, such as a lamp, electric motor, etc. The quantity of electrical energy delivered to any device is measured in **watts**, and for a direct current circuit it is equal to the product of the voltage at the terminals of such a device times the current flowing through it. This can be formulated, as follows:

$$W = V \times C \dots\dots\dots (4)$$

where W is the number of watts, V is the voltage and C is the current in amperes.

The practical unit of electrical energy in large machines is the Kilowatt, equal to 1000 watts.

MAGNETIC EFFECT OF AN ELECTRIC CURRENT.

The magnetic forces created in the space surrounding a conductor, in which an electric current is passing, are in every way similar to the magnetic forces generated by an ordinary magnet. It is a well-known fact, that the space in the vicinity of any magnetic substance is filled with forces which are arranged in definite paths along imaginary lines. These forces have definite strengths and directions at each point and are known as the **Lines of Force**. The space occupied by such lines of magnetic force is called the **Magnetic Field**.

Fig. 27 shows the arrangement of such a field in a horizontal plane, due to the presence of a bar magnet marked N. S. The lines of force have a similar arrangement in all other planes passing through the magnet along its longitudinal axis N. S.

The passage of any appreciable amount of current in a conductnig wire sets up around it a magnetic field, the direction of the lines of force depending upon the direction of the current in the

wire. Fig. 28 shows the general distribution of these lines of force, which is such that if we were to look in the direction of the current, the looping

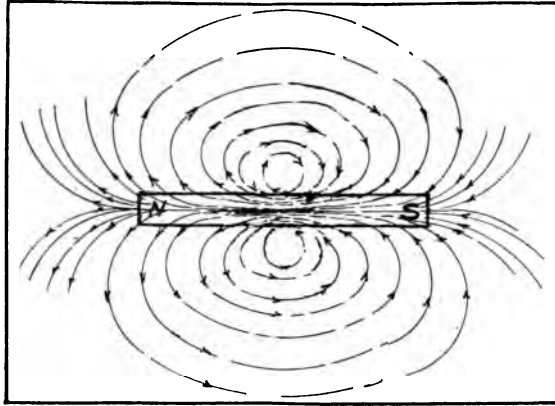


Fig. 27

lines of force would be arranged around the wire in a clockwise direction, i. e., from left to right

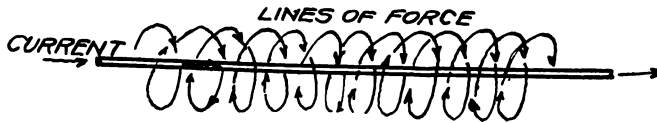


Fig. 28.

above the wire, and from right to left below the wire.

In a **coil** of wire made up of many turns, as shown in Fig. 29, these lines of force all enter the coil by one end and leave it by the other, the field of force being similar in its nature and distribution to the one surrounding an ordinary bar magnet.

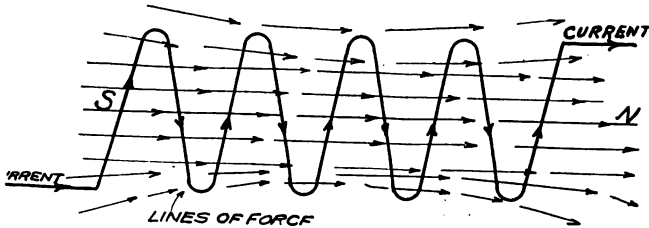


Fig. 29.

Such a coil of wire is called a **solenoid**, and if a soft iron core be placed inside of the coil, the device becomes an **electromagnet**, i. e., a magnet which depends in its action upon the flow of an electric current in the coil. As soon as the electric circuit is opened and the current stops flowing, the iron core loses its magnetism, because there are no lines of force passing through it. But when the circuit is closed, the current generates magnetic lines of force inside of the coil and, since soft iron is a good medium for magnetic forces, it becomes temporarily magnetized and acts in every way like an ordinary steel magnet.

THE PRINCIPLE OF ELECTRO-MAGNETIC INDUCTION.

The transformation from electrical to magnetic energy is reversible, i. e., by means of a magnet we can produce an electric current in a closed conductor, providing the lines of force surrounding the magnet are cut or crossed by the moving conductor. This can be accomplished either by moving the conducting circuit in the field of the magnet, as is done in the modern electrical generator or **dynamo** machine, and in the small **magneto** used for telephone circuits, ignition, etc.; or, we can have the conductor stationary with respect to the magnet and produce the required effect of cutting the lines of force in the field, by constantly varying the strength of the magnetic field surrounding the conductor.

In an electro-magnet we can easily change the strength of its magnetism by rapidly making and breaking the flow of current used to magnetize it. The process of generating electricity in the above manner is known as **electro-magnetic induction**, and the voltage generated in a conductor by induction will depend upon the rate of cutting of the lines of force and upon the **number of turns of wire** in the conductor, in case it is built in the form of a coil. This, briefly, is the theory of operation of the **induction coil** used for ignition. This device is made up of two independ-

ent coils insulated from one another, one coil called the **primary**, having a small number of turns and acting as the elector-magnet; and, the other coil, or the **secondary** with many turns of wire serving as the conductor in which the induced electricity is generated. The voltage developed in the secondary coil is, therefore, much larger than the voltage in the primary coil, in the ratio of their respective number of turns. The rapid making and breaking of current in the primary coil is produced by an ingenious device called the **interrupter, trembler or vibrator**, similar in every respect to the same contrivance used for operating the ordinary electric bell.

IGNITION CIRCUIT OF A SINGLE CYLINDER ENGINE.

The electric spark used to ignite the charge in the gas motor, may be produced by quickly breaking a circuit in which a current is flowing. This sudden opening of the circuit produces a heating effect and a spark at the point of break in the same mannner as a swiftly moving body, if stopped suddenly, will generate a lot of heat at the point of impact. This is called the **make and break** system of ignition, and it is used on many large stationary engines. On account of the tendency of the current to continue its flow, the point of breaking is easily bridged over in a circuit having low voltage but requiring a great deal

of electrical inertia, or **induction**. The ignition circuit of a single cylinder motor using the make-and-break system consists of a low-voltage source of energy, furnished by either a dry or storage battery, or a magneto; also, of a primary induction coil to add inertia at the break; a switch; and an **igniter**, or a device for breaking the circuit, installed in the cylinder and controlled from the crank shaft of the engine.

Fig. 30 is a simplified wiring diagram of the ignition circuit of a single cylinder engine using the make and break system. The energy is supplied either from a magneto (M) or from a battery (B). The switch (S) is wired in such a manner as to connect either the positive terminal of the magneto or one terminal of the induction coil (C) to the igniter (I). The other end of the induction coil is connected to the positive pole of the battery. By the term **positive** is understood the point from which the current is flowing, and the **negative** terminal is the point at which the current returns from the outside circuit. The part of the igniter at the other end of the break is connected to the frame of the engine or is **grounded**, which means that it makes a direct connection to the ground.

The negative terminals of the battery and the magneto are also grounded as indicated in Fig. 30. When the switch is connected to the induction coil, the path of the current is as follows:

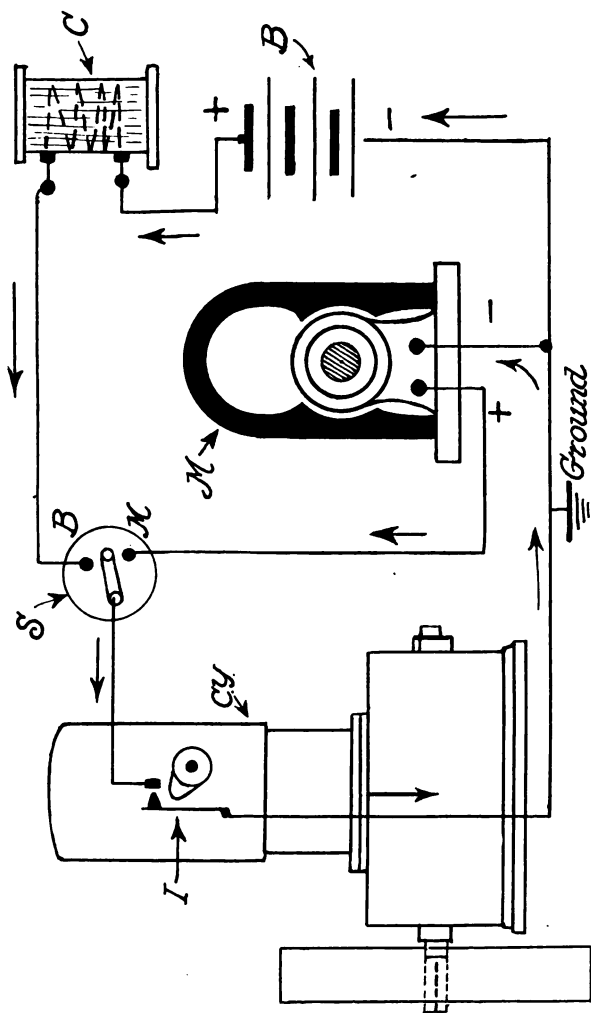


Fig. 30~Diagram of Connections of the Make and Break System for the Single Cylinder Engine.

Positive pole of battery, coil, switch, igniter, engine frame, ground and negative pole of battery. With the switch connected to the magneto, the battery and induction coil are cut out, and the magneto is included in the circuit.

The **igniter** consists of a stationary conductor which receives the current. This conductor is insulated from the cylinder, and screwed into the walls of the combustion chamber. A movable metallic point is in contact with this conductor, this movable point being attached to a spring in such a manner that when it is released it pulls the point of contact quickly away from the stationary conductor, and the break in the circuit is made. Usually the spring is operated by a cam or a rocker arm attached to a shaft which is driven from the crank shaft of the engine, so that the break in the circuit occurs at the proper point of the cycle. By adjusting the position of this cam, the spark can be either advanced or retarded.

Fig. 31 is a picture of a common type of igniter formerly used in the Fairbanks-Morse gas engine.

Another very common method of generating the spark in the combustion chamber is by providing a permanent gap in the electric circuit and forcing the current across it by means of high voltage. This is known as the "**jump-spark-system**" of ignition, and it is used on practically all gas motors driving vehicles, motor boats and air-planes. It has the advantage of doing away with

movable contacts in the cylinder, and it is capable of closer regulation. It is also safer and more economical than the make and break system since the circuit is normally open and current flows



Fig. 31
Common Type of Igniter.

through it only during the instant when the air gap is crossed, or **jumped**, by the spark. The elements constituting the jump-spark ignition system are as follows:

- (1). **Source of power**, such as
 - (a). Dry Cells,
 - (b). Storage Cells,
 - (c). Low Tension Magneto,
 - (d). High Tension Magneto.
- (2). **Devices for raising the voltage.**
 - (a). Induction Coil,
 - (b). Vibrator,
 - (c). Condenser.
- (3). **Device for making the spark.**
 - (a). Spark Plug.

- (4). **Controlling** devices.
 - (a). Hand-switches,
 - (b). Magnetic Switches,
 - (c). Commutator, or Timer,
 - (d). Master Vibrator, or Synchronizer,
 - (e). Timing Shaft and Mechanism.
- (5). **Measuring** Instruments.
 - (a). Volt-meter,
 - (b). Ammeter.

DRY CELLS.

Electrical power can be produced on a small scale by making use of the **chemical** forces of various substances, called "elements", which possess a stored or hidden amount of electricity and are capable of generating an electrical pressure when they are combined in the form of a **cell**. The two elements used in the simplest, or **voltaic** cell, are copper and zinc. These are acted upon by a solution of sulphuric acid, which produces the chemical action necessary for generating electricity.

The usual voltage of such a cell is about 1 volt, and by closing its terminals, or **poles** through a conductor we can obtain a steady current flowing through the circuit. There are many other types of such cells, usually termed **wet** cells on account of the requirement of some liquid acid for their operation. It is obvious that these cells can not be conveniently employed in any gas motors used

for transportation, on account of the trouble of acid splashing and the frequent renewals of elements required in this type of cell. This objection has been largely overcome by the so-called

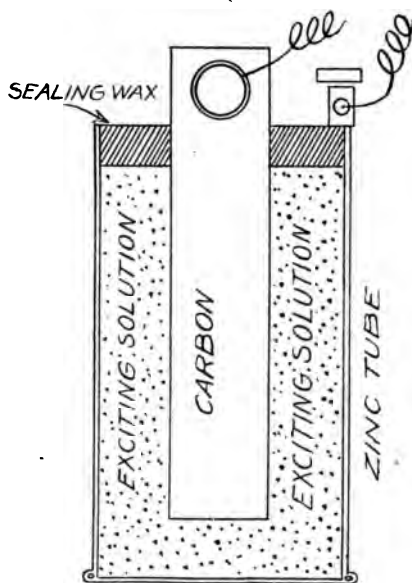


Fig. 32~ Burnley Dry Cell.

“dry-cell”. It is made up of zinc and carbon as the principal elements, and it has its acid in the form of a semi-liquid **paste**, enclosed in a tight metallic container, so that the paste can not easily spill or deteriorate. These dry cells are not re-

newable, but they are much cheaper than the wet types, and they are thrown away after the elements are used up.

A common type of dry cell is the so-called "Burnley" cell, shown in Fig. 32. In this cell one element is made up of a zinc tube, which also serves as a protective container. The other element is placed inside the tube, and surrounded by a paste-like chemical mixture, made up as follows:

1 part sal-ammoniac	3 parts plaster
1 part chloride of zinc	1 part flour
1 part peroxid of manganese	2 parts water
1 part granulated carbon	

The top of the tube is tightly sealed with some insulating compound, and the terminals are brought out for connection. The voltage of this cell equals 1.4 volts, and the internal resistance is about 0.3 ohms.

CELLS IN SERIES.

In case it is necessary to obtain a larger voltage than that available from a single cell, several of them can be connected in series, i. e., the positive pole of one is connected to the negative pole of the next one, etc., and the poles of the end cells are used as the terminals to be connected to the external circuit. Any combination made up of several cells is called a **battery**. Fig. 33 shows a battery of cells connected in series.

CELLS IN PARALLEL.

In case a large current at low voltage is desired, the parallel connection, as shown in Fig. 34, can

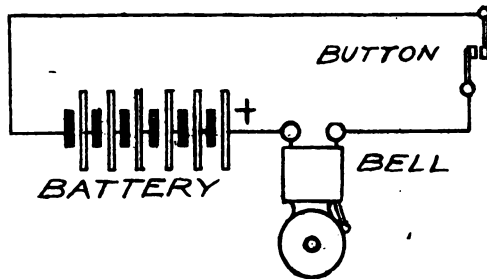


Fig.33~ Cells in Series

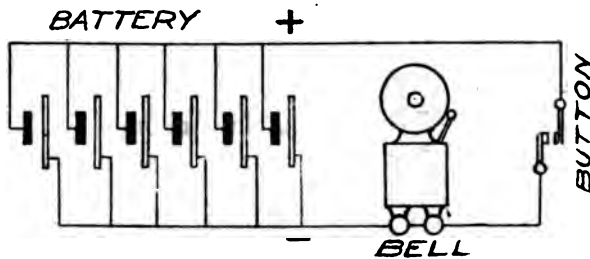


Fig.34~Cells in Parallel.

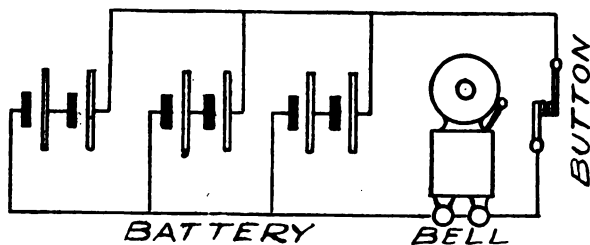


Fig. 35~Series-Parallel Connection.

be used. In this arrangement all the positive poles are connected to one wire, and the negative poles to the other wire, so that the terminals of each cell are connected across the same two points.

SERIES-PARALLEL CONNECTION.

In some instances, to obtain the maximum amount of current with a given number of cells, it is advisable to use a combination of both methods described above, i.e., the cells are connected in separate series groups, and these groups are connected in parallel. Fig. 35 illustrates such a connection.

STORAGE BATTERIES.

The ordinary type of primary cell cannot be used for relatively large ignition systems, because its power is very limited, and it requires frequent replacing every time the cell "runs out", or becomes exhausted.

The most practical type of battery, which can be used in all cases whenever electrical power has to be used in considerable quantities independent of a central station, is the **storage battery**.

It has a relatively large current and power capacity, and it can be used over and over again for years by exercising proper care in its maintenance.

The **storage cell**, like any other type of electric cell, is a device for converting chemical into electrical energy, but it differs from the ordinary primary cell in that when the chemical energy is all used up, it can be restored to the cell by putting

into it a new equivalent supply of electrical energy, which is thus **stored up** for later use. In general, this is accomplished by the electric current producing a chemical reaction opposite to that which goes on while the battery is being used.

The process of storing up electrical power in the battery is called **charging** it, and using that power is termed **discharging** the battery. On charging the cells, the current is sent through the battery in the opposite direction to that in which it flows when it is discharging, or doing work. On charging, the positive side of the supply circuit is connected to the positive pole of the battery, and the negative side to the negative pole; so that in this case the current flows **to the positive pole** instead of **from it**.

The most common types of storage batteries are made up of the following parts:

Positive Plate. Active material: Lead peroxide, a hard substance of reddish-brown color, inserted in a framing of lead.

Negative Plate. Spongy lead of dark-gray color, very soft, imbedded in a grid of lead.

The acid, or **Electrolyte**. A dilute solution of sulphuric acid. Each plate is supplied with a projecting terminal for connection with the other elements of the battery, the plates being insulated either by glass or hard rubber. The containing vessel is usually made of wood, lined with lead, to withstand the deteriorating action of the acid.

Fig. 36 shows a modern type of a storage battery made by the Gould Company. When the cell is completely discharged, then the active

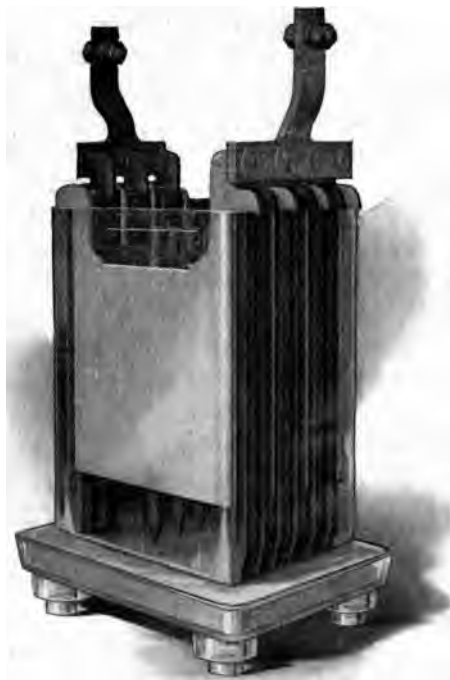


Fig. 36

material of both the positive and the negative plates are in the form of lead sulphate, and the electrolyte is practically reduced to water.

When the charging current passes through the cell, the lead sulphate in the negative plate loses the sulphate part, becoming pure, spongy lead; the positive plate also loses the sulphate, but it combines with the escaping oxygen gas, forming lead peroxide. In the meantime the water combines with the liberated sulphate, becoming dilute sulphuric acid. On discharging, the reverse process takes place, the battery **delivering** instead of **receiving** current generated by the potential difference now existing between the lead peroxide and the pure lead, this potential energy getting smaller as the cell is gradually used up.

The active material of the cell is supported to the lead framing in various ways, the most common of these being the **Plante** and the **pasted** types of plates. In the Plante plate, the active material forms the outer portion of the supporting grid and is an integral part of it, while in the pasted plates the material is prepared in a form of plastic paste, which is spread over the plate by some mechanical means. Both methods have their advantages and disadvantages. The Plante type is more solid and permanent, but it is liable to cause buckling of the plate, due to the unequal expansion of its two portions; while the pasted type is free from buckling, but its active material is subject to crumbling and rapid deterioration, sometimes causing a short circuit in the cell when the battery is used roughly.

The composition of the electrolyte never reaches the stage of pure water, but when the battery is near the point of complete discharge, it contains only from 5 to 10 per cent of acid. Taking the density of water as unity, the density of the same volume of strong acid can be taken as 1.970, that is, 1 cubic foot of the very strongest acid would weigh 1.970 times as much as 1 cubic foot of water under the same conditions of pressure and temperature. The commercial sulphuric acid has usually a specific gravity (usually written sp. gr.) = 1.835, and some stronger forms of the acid have a sp. gr. = 1.842. Table 3 shows the specific gravity of sulphuric acid in its various mixtures with water, by weight.

We see from this table that with the change from pure acid to a very dilute mixture the specific gravity of the liquid changes accordingly, varying from about 1.215 at full charge to 1.174 at discharge. This fact gives us a very easy method of finding the condition of the battery at any time, by testing the density of the electrolyte by means of a special hydrometer.

The temperature of the cells is usually also measured at the time the density of the acid is tested, and from these measurements we can find the amount of charge left in the battery which can still be utilized without discharging it to a dangerous point.

The ordinary values of efficiencies of the differ-

Sulphuric Acids. Mixture with Water by Weights.

Sp. Gr.	Wt. in lb. per cubic foot	Per cent. of 1.835 acid	Lb. of 1.835 acid in 1 cu. ft.	Per cent. of 1.842 acid
1.000	62.37	0.00	0.00	0.000
1.007	62.81	1.00	0.63	0.935
1.014	63.24	2.50	1.58	2.337
1.021	63.68	3.66	2.33	3.422
1.028	64.12	5.00	3.21	4.675
1.036	64.62	6.00	3.88	5.610
1.043	65.05	7.00	4.55	6.545
1.051	65.55	8.00	5.24	7.480
1.058	65.99	9.00	5.94	8.415
1.066	66.49	10.25	6.82	9.584
1.074	66.99	11.50	7.70	10.752
1.082	67.48	12.50	8.44	11.687
1.090	67.98	13.60	9.25	12.716
1.098	68.48	14.70	10.07	13.744
1.107	69.04	16.00	11.05	14.960
1.115	69.54	17.00	11.82	15.895
1.124	70.10	18.25	12.79	17.064
1.133	70.67	19.60	13.85	18.326
1.142	71.23	21.00	14.96	19.635
1.151	71.79	22.00	15.79	20.570
1.160	72.35	23.25	16.82	21.739
1.169	72.91	24.50	17.86	22.907
1.179	73.53	26.00	19.12	24.310
1.188	74.10	27.25	20.19	25.479
1.198	74.72	28.50	21.30	26.647
1.208	75.34	30.00	22.60	28.050
1.218	75.97	31.25	23.74	29.219
1.229	76.65	32.75	25.10	30.621
1.239	77.28	34.00	26.28	31.790
1.250	77.96	35.50	27.68	33.192
1.261	78.65	37.00	29.10	34.595
1.272	79.33	38.37	30.44	35.876
1.283	80.02	39.75	31.81	37.166
1.295	80.77	41.25	33.32	38.569
1.306	81.46	42.62	34.72	39.850
1.318	82.20	44.00	36.17	41.140
1.330	82.95	45.50	37.74	42.542
1.342	83.70	47.00	39.34	43.945
1.355	84.51	48.50	40.99	45.347
1.368	85.32	50.00	42.66	46.750
1.381	86.13	51.50	44.36	48.152
1.394	86.94	53.00	46.08	49.555
1.408	87.82	54.50	47.86	50.957
1.421	88.63	56.00	49.63	52.360
1.436	89.56	57.50	51.50	53.762
1.450	90.44	59.00	53.36	55.165
1.465	91.37	60.50	55.23	56.567
1.479	92.25	62.00	57.20	57.970

Table No. 3

TABLE No. 3. Continued

10000	10000	10000	10000	59.37
10000	10000	10000	10000	60.77
10000	10000	10000	10000	62.17
10000	10000	10000	10000	63.59
10000	10000	10000	10000	65.16
10000	10000	10000	10000	66.66
10000	10000	10000	10000	68.25
10000	10000	10000	10000	69.75
10000	10000	10000	10000	71.24
10000	10000	10000	10000	72.80
10000	10000	10000	10000	74.33
10000	10000	10000	10000	76.01
10000	10000	10000	10000	77.60
10000	10000	10000	10000	79.47
10000	10000	10000	10000	81.34
10000	10000	10000	10000	83.21
10000	10000	10000	10000	85.66
10000	10000	10000	10000	87.06
10000	10000	10000	10000	87.53
10000	10000	10000	10000	88.54
10000	10000	10000	10000	89.44
10000	10000	10000	10000	90.50
10000	10000	10000	10000	91.93
10000	10000	10000	10000	93.30

capacities of lead storage batteries vary from 20 to 30 amp. hours per volt. This low figure is a consequence of some defects that are peculiar to lead. Most of the battery troubles can be traced to the effects of over discharging. The removal of the plates of the active material from the electrolyte when the battery is allowed to discharge below the range between the normal voltage of 2.1 and 2.2 volts, then the active material is deposited upon both plates and the plates are very hard to bring back to their normal state by merely recharging. The active plate is a very poor conductor of electricity if it is allowed

penetrate to a considerable depth of the plates, it prevents the charging current from acting freely upon them in the usual manner.

This effect of accumulated lead sulphate is called **sulphation**, and it is in many cases the origin of all other battery troubles, such as loss of capacity, loss of voltage, burning, shedding of active material, etc.

The only way in which this trouble can be remedied is by overcharging the battery at higher rates than normal, but being careful not to allow the temperature of the battery to rise above 110°F. during this process. The usual practice is to start the charge at about one-half hour rate, which is about sixteen times the normal current capacity of the cell. After a few minutes this rate is changed to a one-hour rate, then to a two-hour rate, etc., keeping close watch of the temperature, and continuing this process until both plates begin to let off gas freely and the desired voltage between the plates is reached. Sometimes this process has to be repeated several times before the battery is completely recovered from the effects of sulphation.

The presence of impurities is liable to start **local action** the same as in primary cells, and it also causes short circuits between plates by opening a metallic patch in the electrolyte. The remedy for that is, obviously, to use pure materials, and to keep

TABLE No. 3 (Continued)

1.495	93.24	63.50	59.21	59.372
1.510	94.18	65.00	61.22	60.775
1.526	95.18	66.50	63.29	62.177
1.542	96.17	68.00	65.40	63.580
1.559	97.23	69.70	67.77	65.169
1.576	98.30	71.30	70.09	66.665
1.593	99.36	73.00	72.53	68.255
1.611	100.48	74.60	74.96	69.751
1.629	101.60	76.20	77.42	71.247
1.648	102.79	77.87	80.04	72.809
1.666	103.91	79.50	82.61	74.332
1.686	105.16	81.30	85.50	76.015
1.706	106.40	83.00	88.31	77.605
1.726	107.65	85.00	91.50	79.475
1.747	108.96	87.00	94.80	81.345
1.768	110.27	89.00	98.14	83.215
1.790	111.64	91.62	102.29	85.665
1.801	112.33	93.12	104.60	87.067
1.807	112.70	94.00	105.94	87.830
1.812	113.01	94.70	107.02	88.544
1.818	113.39	95.66	108.47	89.442
1.824	113.76	96.80	110.12	90.508
1.830	114.14	98.33	112.23	91.939
1.835	114.45	100.00	114.45	93.500

ent types of lead storage batteries vary from 50 per cent to 75 per cent. This low figure is due to many troublesome defects that are peculiar to them. Most of these battery troubles can be traced back either to the effects of over discharging, or to the presence of impurities in the active material or in the electrolyte. When the battery is allowed to discharge until the voltage between the elements becomes less than 1.70 volts, then the accumulation of lead sulphate upon both plates becomes so permanent that it is hard to bring the battery back to its original state by merely recharging it; because lead sulphate is a very poor conductor of electricity, and so if it is allowed to

penetrate to a considerable depth of the plates, it prevents the charging current from acting freely upon them in the usual manner.

This effect of accumulated lead sulphate is called **sulphation**, and it is in many cases the origin of all other battery troubles, such as loss of capacity, loss of voltage, burning, shedding of active material, etc.

The only way in which this trouble can be remedied is by overcharging the battery at higher rates than normal, but being careful not to allow the temperature of the battery to rise above 110°F. during this process. The usual practice is to start the charge at about one-half hour rate, which is about sixteen times the normal current capacity of the cell. After a few minutes this rate is changed to a one-hour rate, then to a two-hour rate, etc., keeping close watch of the temperature, and continuing this process until both plates begin to let off gas freely and the desired voltage between the plates is reached. Sometimes this process has to be repeated several times before the battery is completely recovered from the effects of sulphation.

The presence of impurities is liable to start **local action** the same as in primary cells, and it also causes short circuits between plates by opening a metallic patch in the electrolyte. The remedy for that is, obviously, to use pure materials, and to keep

the battery in a place protected from dust and other foreign substances.

Except the troubles which can be remedied as outlined above, the lead battery has certain other inherent defects which make it objectionable in many cases. In the first place, the lead battery is rather heavy; also, this battery, being open on top, is not adapted to use where there are many jolts and jars, because this will cause the electrolyte to spill and splash over the edges. Furthermore, the gases issued from the lead battery are very disagreeable and injurious to the health of the attendants, and this makes it objectionable for use in small, closed rooms, such as are found on many vessels, and especially on submarines.

Due to the use of acid, the parts are liable to get quickly deteriorated from corrosion, and since they are all lined with lead, the battery as a whole is heavy and clumsy to handle.

Many inventors have tried to improve the storage battery so as to get rid of the above defects, and so far the most successful of these attempts has been the storage battery invented by Thomas A. Edison, called the "Edison storage battery", made up of the following parts:

Positive Plates. Nickel hydroxid and pure metallic nickel in perforated tubes of nickered steel, mounted on a steel grid.

Negative Plates. Iron oxid in thin rectangular

pockets of perforated nickeled steel, mounted on a steel grid.

Electrolyte. Potassium hydrate (21 per cent solution), with a small amount of lithium hydrate. The density of electrolyte remains the same on charge and discharge.

Insulation. Extra-hard rubber.

Container. Pressed steel, nickel-plated, with welded seams and sealed cover.

Trays. Light wood crates, with steel cradles for holding cells rigidly in position.

Connections. Copper wire, attached to steel lugs, nickel-plated.

Fig. 37 shows one complete element, and Fig. 38 is a view of a portable type of battery.

The advantages claimed by the Edison Storage battery are:

1. Its long life.
2. Light weight (about one-half of the lead battery).
3. Ruggedness of construction.
4. Ease of operation (no sulphation, no sediments, corrosive fumes, lead burning, etc.).

Against these we have to point out the high cost of the Edison cell (about twice the lead cell), the complicated composition of the elements, making it harder and more expensive to renew them; the rather low watt-hour efficiency, and the low average voltage per cell, requiring more cells in series

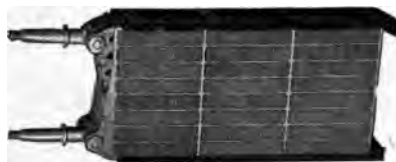


Fig. 37

Complete Element with Insulators
Complete Element of the Edison Battery removed
from its Container



Fig. 38

Portable Cells Sealed
The Edison Nickel - Iron - Alkaline Storage Battery

to make up the required voltage. But with all these disadvantages, which are only of minor importance, the Edison storage battery is a great improvement upon the lead and sulphuric acid type, and it has done a great deal toward enlarging the field of application of storage batteries.

INDUCTION COIL AND CONDENSER.

The function of the induction coil is to raise the voltage at the spark gap to a value large enough to overcome the resistance of the air. Since the voltage delivered from the battery or the magneto is only from 6 to 10 volts, and the voltage required at the gap is at least 6000 volts, the ratio of turns of wire in the primary and secondary coils should be not less than 1000. The primary coil is therefore made of very few turns of large-sized wire. This is completely insulated; and the secondary coil, made up of many turns of very fine wire, is wound around the primary coil. The primary circuit is provided with a **vibrator** for rapidly opening and closing the circuit, and the **condenser**, connected across the terminals of the vibrator gap, to reduce the sparking.

The main connections of the ignition circuit for a single cylinder engine using the "jump-spark" system is shown in Fig. 39.

THE PRIMARY CIRCUIT.

Referring to the Wiring diagram (Fig. 39), the primary circuit is made up as follows: The power

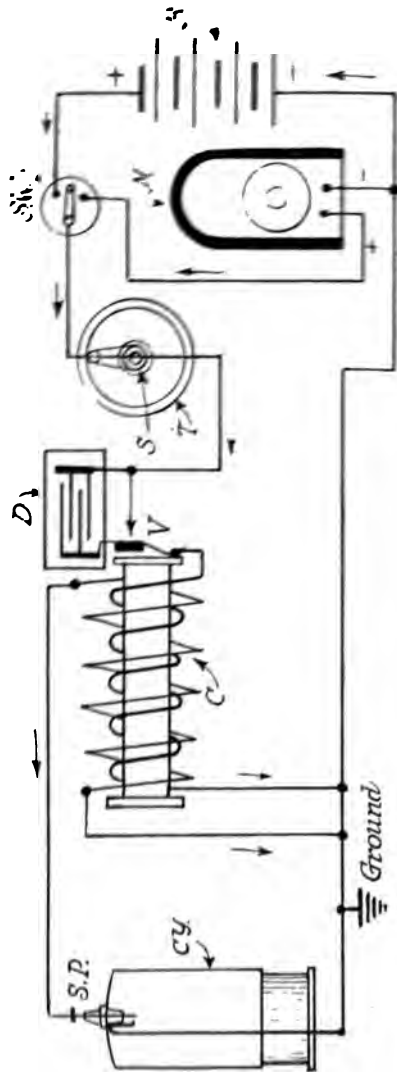


*Fig.39~ Wiring Diagram of Jump-Spark System
for Single Cylinder Engine.*

is furnished either by battery (B) or magneto (M), which are both connected to a double-throw switch (SW). The other terminal of the switch is connected to the stationary sector of the **timer or commutator** (T). The sliding contact is made in the commutator by a roller attached to the **timing shaft** (S), which is driven from the crank shaft. This closes the primary circuit only during the brief period of the cycle when the spark in the combustion chamber is required. The movable part of the commutator is connected to the induction coil (C), the current passing through the vibrator (V) and the primary coil winding. The other terminal of the primary coil and also the negative terminals of the battery and the magneto are all grounded.

THE SECONDARY CIRCUIT.

The variations in magnetic strength around the primary winding induces a current of high voltage in the secondary winding of the induction coil. This high voltage current passes to one side of the air gap located in the combustion chamber, through the **spark plug** (S. P.) inserted in the cylinder. The other side of the gap, as well as the other terminal of the secondary winding of the induction coil are both grounded.

SPARK PLUG.

The spark plug consists mainly of an insulated conductor provided at one end with a binding post for connecting it to the secondary winding of the

induction coil, and at the other end having a terminal, forming one side of the air gap. The insulated portion of the spark plug is surrounded by a metal sleeve threaded on the outside in order to provide means for screwing it into the opening made for it in the cylinder wall. The connection is made gas-tight by means of a bushing and special packing, and to this outside part of the spark plug is attached the second terminal of the air gap. In this manner it connects the spark plug directly with the engine frame, which serves as a **ground** for all the negative terminals of the ignition system. Fig. 40 shows some common types of spark plugs made by Champion Spark Plug Co., the first two with porcelain insulation, and the third one having a mica insulator.

IGNITION CIRCUIT FOR A MULTIPLE CYLINDER ENGINE.

In gas engines made up of more than one cylinder, the general scheme of connections is similar to the single-cylinder ignition system with this principal difference, that the number of induction coils is equal to the number of cylinders which are provided with individual spark plugs.

COMMUTATOR.

The **commutator** is in this case made up of as many sectors as there are firing circuits, the connections being arranged in such a manner as to



Fig. 40—Spark Plugs
Manufactured by Champion Spark Plug Co.

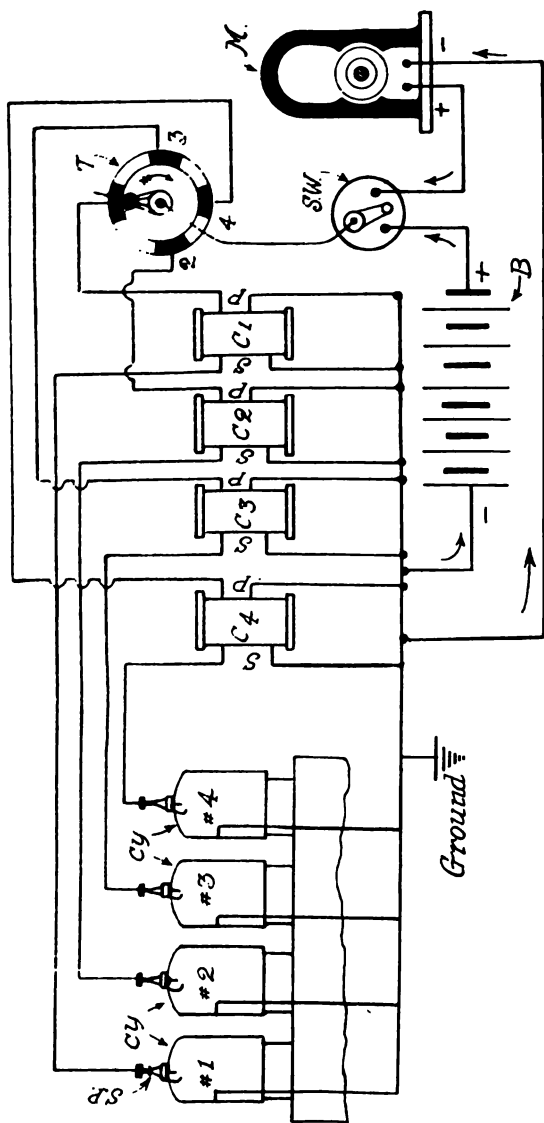


Fig. 41~Wiring Diagram of the Jump Spark Ignition System for a Four-Cylinder Engine

~Legend~

- Cy~ Cylinders
- Sp~Spark Plugs
- T~Commutator
- C~Induction Coils
- P~Primary Terminals
- S~Secondary Terminals
- SW~Switch
- M~Magneto
- B~Battery

provide for the proper order of firing. As stated before, in a four-cylinder motor the usual order of firing is 1-3-4-2. The four wires leading to the commutator sectors are therefore connected in the above order so that, as the timing shaft revolves, the contacts are made, first with sector leading to cylinder No. 1, then with No. 3, then with No. 4, and finally with No. 2. The simplified wiring diagram of such an ignition system for a four-cylinder motor is shown in Fig. 41, where the letters have the same meaning as in Fig. 39, with the numbers attached indicating the circuit of the proper cylinder.

ADVANCING AND RETARDING THE SPARK.

By making the outer housing of the commutator movable, and attaching the conducting sectors to it, we can provide for their adjustment to a position forward or backward of the normal, so as to advance or retard the time of ignition in all the cylinders. This is known as advancing or retarding the spark, which is thus easily controlled by a regulating lever within the reach of the operator. The effects of timing the spark were discussed in Chapter I, from which we can see, that a spark retarded too far tends to heat up the cylinder, while an over-advanced spark may cause overstrain in the cylinder, also preignition and backfiring.

On starting the engine the spark should be retarded until the motor has attained full speed, to

avoid the danger of sudden reversal in case ignition should occur before the end of the compression stroke.

LOW TENSION AND HIGH TENSION MAGNETO.

The common type of magneto used for ignition of small gas motors is made up of a permanent horse-shoe magnet, and a rotary part, termed the **armature** revolving in this constant magnetic field. This armature has a single insulated winding, consisting of a relatively small number of turns of heavy wire in which the current is generated by induction. This type of machine is known as a **low-tension magneto**, since it generates current having a low voltage which has to be raised for ignition purposes by means of the induction coil.

In many modern types of gas motor the magneto is built with a double armature winding, one coil being wound around the insulation of the other one in the same manner as in the induction coil. The inside, or **primary** winding consists of a small number of turns of heavy wire, while the **secondary** winding is made up of a large number of turns of very fine wire. The field is energized by a permanent magnet. This arrangement induces a high voltage in the secondary winding of the magneto when the armature shaft is driven at normal speed from the crank shaft of the motor. Such a

type of generator is termed a **high-tension magneto**, and it has the advantage of simplicity in ignition wiring, since it saves the use of induction coils, vibrators and condensers. The secondary terminals of the magneto are connected directly to the spark plugs of the engine. The primary terminals of the high-tension magneto are connected to a **distributor** which makes the connections to the proper firing circuits and to the **timer** mechanism for regulating the order and time of ignition.

In large sized motors having multiple cylinder engines, where a low tension magneto is used, the various induction coils are frequently operated through a single vibrating device called a **synchronizer** or master-vibrator.

This usually consists of several single vibrators corresponding to the number of cylinders, all connected in series, so that their action depends upon the same current and they are prevented from operating out of step due to the variation in their mechanical lag, or inertia. With the high tension magneto the distributor performs a similar function.

The advantages gained by the use of the high tension system are partly minimized, due to the greater danger of break-downs on account of the high voltage, which requires better insulation and greater care in handling it.

THE MAGNETIC SWITCH.

In many recent types of gas motor the ignition system derives its energy from a small **dynamo** operating in connection with a storage battery, and supplying power for lighting, starting and other electrical devices. The main difference between a dynamo and a magneto lies in the fact that the magnetic field in the magneto consists of a permanent magnet, while in the dynamo the field is an electro-magnet, the field coils being energized by a portion of the current generated in the armature. The gas motor using such a system is started on the storage battery, which is connected to the ignition circuit until the current supplied by it becomes too weak for the demands of the system. Then the ignition current is switched to the dynamo which, running at full capacity, can supply the power required for ignition while the battery is being recharged by another portion of its current. This is called "Floating" the storage battery on the line.

The process of switching from one source of power to the other can be done automatically by the use of a **magnetic** switch, which is a device operating by means of a solenoid or electro-magnet. When the current in the battery circuit falls below a certain value due to its being partly "run down", the solenoid is weakened and the switch, which is attracted by its magnetism, is released,

automatically connecting the ignition system and the battery to the dynamo.

When the battery is fully charged, the dynamo is automatically cut out of the ignition circuit, and the battery is connected as before. The use of the magnetic switch makes the system automatic and prevents the danger of either overcharging the battery or causing sulphation due to running it down too low.

MEASURING INSTRUMENTS.

The strength of the power supplied to the ignition system may be indicated by means of electrical measuring instruments connected in the circuit. The **voltmeter** measures the electrical pressure or voltage when its terminals are connected across the positive and the negative terminals of the circuit. Great care must be taken to prevent the voltmeter from being connected across a circuit having a voltage higher than the one for which the instrument was designed, as indicated on its scale. The strength of the current in any part of the ignition system is indicated by placing an **ammeter** in series with that circuit. The same precaution about using the instrument in the proper circuit should be applied to the ammeter, which should be normally switched off, except during the periods when current readings are made. In large motors of modern construction these and other instruments and switching devices are all mounted

on a small switchboard, properly insulated from the metal framework and protected from all moisture and dirt.

IGNITION TROUBLES.

In general, all the common electrical ignition troubles can be finally traced back to the following defects in the system: either the flow of current is too strong, or it is either partially or entirely obstructed. To the first category belong all sorts of overloads and short-circuits; breaking down of insulation due to moisture, corrosion or overheating; magneto running at too high a speed, and an overcharged battery. The flow of current is more or less restricted by the presence of dirt and oil at the connections or in the spark plugs; breaking down of condensers or induction coils; defective, punctured or loose wiring and connections; loss of magnetism in the magneto or dynamo; weak, or sulphated batteries; magneto running at too low a speed; defective switches; worn out equipment; imperfect timing mechanism.

REMEDIES.

It is hardly necessary to emphasize the importance of correct ignition to the proper operation of the gas motor. A failure of the spark due to the defects enumerated above in any of the cylinders of a multiple-cylinder engine means **misfiring**, or

an explosion missed, and the fuel being thrown away at exhaust without having performed any useful work. If the trouble is not remedied quickly, the power output and efficiency of the motor will be considerably reduced, and, in severe cases, when several cylinders are thus affected, the motor will finally stop on account of lack of power. In aviation such a condition often leads to the loss of life and the wrecking of the machine.

Many ignition troubles may be avoided by keeping the system protected from dirt, moisture and acids; by regulating the oil supply to avoid overheating due to poor lubrication, and to prevent insulation of the air gaps caused by an excess of oil in the cylinder; and, finally, by careful inspection before the motor is started.

When trouble occurs during the operation of the motor, which is usually made evident by lack of power, the machine should be stopped at the first opportunity and the source of trouble located. The magneto and battery should be tested by the voltmeter, then the wiring must be examined and tested by placing the ammeter in each separate circuit and observing if the circuit is broken at any point. It is very important to have on hand a quantity of wire and insulating tape and as many duplicate parts as possible, especially spark plugs, binding posts and switches. In order to locate the cylinder which is misfiring, it is often necessary to disconnect the wires at the spark plugs, one at

a time, until we reach the cylinder which will not cause the motor to slow down in speed when that spark plug is disconnected. The faulty spark plug should be removed and the opening carefully cleaned before a new one is inserted. Any troubles in the batteries, magnetos, coils or in the timing mechanism cannot be quickly remedied, so that particular pains must be taken to have these parts in good working order before the motor is started.

QUESTIONS ON CHAPTER V.

1. State the advantages and disadvantages of the hot-tube system of ignition.
2. Find the total resistance of a circuit made up of 800 ft. of No. 4 copper wire having a resistance of 0.00025 ohms per ft.
3. The circuit described in question 2, is supplied with power from 220 volt mains, D.C. What is the strength of the current passing in the wire, and how much power is delivered to this circuit?
4. What is meant by the term "electro-magnetic induction"?
5. How is the ignition spark produced in the make-and-break system?
6. What equipment is required for an ignition circuit of a single cylinder engine using the make-and-break system?
7. What equipment is required for the ignition

circuit of a four-cylinder single-acting engine using the jump-spark system with a low-tension magneto?

8. State the function and principle of operation of the induction coil.

9. Enumerate the advantages and disadvantages of the Edison storage battery?

10. What is the advantage gained by using a magnetic switch in floating the storage battery on the line supplied by the dynamo?

11. Enumerate the main causes of failure of the electric ignition system.

12. How can the misfiring cylinder be quickly located?

ANSWERS TO QUESTIONS ON CHAPTER IV.

1. In stationary engines the cylinders are usually arranged either in tandem or in duplex, if there is room available for horizontal engines. When space is limited the cylinders are placed vertically in a single row attached to the same bed-plate.

2. The most common types of gas motor used for aviation are the multiple cylinder vertical engines; the V-type motors; the Fan-types; and the star, or radial motors having either stationary or revolving cylinders.

3. The "horizontal-opposed" type engine delivers balanced power with two cylinders and it

has the advantages of simplicity of operation and symmetry of arrangement of its cylinders.

4. When the cranks of a two-cylinder engine are both turned in the same direction the events are evenly distributed, so that we get one power stroke at every revolution of the crank shaft. With the cranks set at 180 degrees to one another, the shaft receives two power impulses during one revolution and no power during the next revolution.

5. The cam shaft of a vertical four-cylinder engine having all valves mechanically controlled has eight cams, arranged each opposite its corresponding valve in the numerical order of the cylinders. When the inlet valve cam of cylinder No. 1 is just ready to lift the rod, the cam of inlet valve No. 2 is about 90 degrees ahead of it, the cam of inlet valve No. 3 is 90 degrees behind it, and inlet cam No. 4 is 180 degrees behind it. The same angular relation exists between the cams operating the four exhaust valves.

6. A single acting two cycle engine having 16 cylinders delivers 16 power impulses per revolution of the crank-shaft.

7. The revolving-cylinder type of motor requires a single cam to control all its valves, it does not need any special cooling system, and it saves the use of a fly wheel and of a muffler.

8. The multiple cylinder motor delivers more balanced power, has a greater range of power and speed, is more reliable, and has small parts with a

large power output. In motor vehicles, the number of cylinders is limited by the allowable speed, also by the loss in efficiency and the more complicated equipment caused by the increased number of cylinders.

9. The rated H.P. of an 8-cylinder automobile engine having a bore of 5 inches is equal to $5 \times 5 \times 8$.

$\frac{\quad}{2.5} = 80$ H.P. (See Chap. I).

2.5

10. The most common cylinder troubles due to defects in the cooling system, are: cracking and overheating, compression leaks, pre-ignition and back-firing.

11. Back-firing may be due to the following causes: ignition being advanced too far; failure of the cooling system; cranking with an advanced spark; accumulation of hot gas in the muffler; hot cylinder; carbon in the cylinder; mixture too weak, or too rich; excess of oil in the cylinder.

12. Before starting the motor, to prevent cylinder troubles, all the parts should be generally inspected, the spark should be retarded, the cooling system filled with water, and the lubrication system supplied with oil; the carbureter should be examined to see that it is adjusted to give the proper mixtures according to the requirements of the motor.

CHAPTER VI.

THE LUBRICATING SYSTEM.

The importance of proper lubrication for the efficient performance of the gas motor has already been pointed out in the previous chapters. The average operator of a gas engine usually realizes the necessity of having a sufficient **quantity** of oil in the cylinder and in the bearings, but, unfortunately, not all of them take the trouble to determine if the **quality** of the oil used is properly suited for the particular requirements of the various parts of his engine. The function of any lubricant, whether it is an oil, grease, graphite or soapstone, is to provide a film of minute globular particles between the two metal surfaces rubbing against one another, so as to convert the sliding friction between them to rolling friction. The difficulty of accomplishing this purpose lies in the fact that many lubricants lose their globular structure known as **vicosity** or **body** at the high temperatures generated in the modern gas motors; and some of them, particularly animal and vegetable oils, contain acids that are injurious to the life of the metals, which are corroded by their action. It is, therefore, important that the qualities of the various lubricants should be carefully investigated

before they are used in the motor to any great extent.

GENERAL QUALITIES OF LUBRICANTS.

As a result of long years of theoretical study combined with practical experience, the following general requirements of lubricants have been established:

(1) The **viscosity** of the lubricant must be great enough to maintain a film of oil between the metal surfaces under operating conditions of temperature, pressure and speed at the bearings.

(2) The **fluidity**, or its freedom to flow must be sufficient to insure a continuous supply at the bearings without losing the qualities of viscosity under operating conditions.

(3) It must not contain any **acids** or other chemicals injurious to the metal.

(4) It must not readily decompose, oxidize or vaporize at the normal working temperatures of the motor.

(5) It should have a high **flash point**, which is the temperature at which the vapor of the oil is ignited.

(6) It should have a high **burning point** consistent with the above qualities.

(7) The lubricated parts should in all cases have a minimum **coefficient of friction**, which is the ratio between the frictional force at the bearing and the total pressure at normal speed.

(8) The oil should be **free from dirt** or any foreign matter tending to gum up the lubricating parts.

(9) It must carry away the heat quickly from the bearings.

CYLINDER OILS.

The proper grades of oil used for lubricating the cylinder should be of mineral origin, having a flash point not less than 500 degrees Fahrenheit, and a burning point not less than 600 degrees Fahrenheit. The specific gravity of a good cylinder oil should be about 25.8 at normal temperature and pressure.

GREASE.

For lubricating the parts of the motor running at relatively slow speeds under pressure, the light cylinder oils do not possess sufficient body to keep the metal surfaces separated. For these parts, such as the transmission gearing, differential gearing and at the axles, a heavier lubricant, or grease is employed. The friction caused by pressure generates sufficient heat at these bearing surfaces to gradually melt the grease and thus keep them automatically lubricated as long as the supply of grease is not used up.

The transmission case of an automobile is usually filled with a very heavy grade of oil, somewhat more fluid than ordinary grease, up to about an inch above the bottom of the sliding gears. This

throws the oil into all the parts of the gearing when the shaft is revolved.

The differential gears are usually packed in heavy Albany Grease which has to be renewed about twice a year.

For lubricating ball-bearings, a lighter form of grease, such as vaseline, is used.

GRAPHITE.

The addition of a special solid lubricant, known as **graphite**, to the oil helps to raise its viscosity without diminishing the rate of flow of the oil. Usually **graphite** is added in the proportion of about one teaspoonful to a pint of oil. It can also be introduced into the cylinder directly by means of an insect gun quill inserted into the opening provided for the spark plug or for the igniter. Care should be taken to prevent an accumulation of **graphite** on the spark plugs, as this tends to short-circuit the air gap and may cause misfiring.

SIGHT FEED OILING SYSTEM.

One of the simplest and most direct methods of lubrication is by the so-called **sight-feed** system, which consists of placing oil cups over the points requiring lubrication, and allowing the oil to flow down into the bearings by gravity through grooves and feed pipes provided for that purpose. The type of oil cup used for this system of lubrication

is often provided with a special indicator placed on top of the cup which shows by its position whether the oil is turned on or shut off. There is also usually provision made for observing the number of drops of oil passing the feed pipe per minute, so as to better regulate the flow of oil to each particular bearing point. The main advantage of the sight feed system lies in its simplicity, but it has the serious drawback of requiring almost constant attention and therefore not being very reliable. When used in addition to other systems of lubrication this direct method often proves a great aid in cases of emergency.

THE SPLASH FEED SYSTEM.

A very common method of oiling single cylinder gas engines is by the "**Splash Lubricating System**". The principal source of oil supply is in this case located at the bottom of the crank case, the oil being kept at a level high enough to allow the crank pin to dip into it at every revolution of the shaft. This splashes the oil in all directions and thus lubricates the bearings and the lower part of the cylinder and the piston which carries it up to the upper parts of the engine. The oil is usually supplied through a large oil cup screwed into the upper part of the crank case and which is refilled as soon as its supply is drawn into the crank case reservoir.

FORCED FEED SYSTEM.

In a gas motor of any considerable size, having more than one cylinder, the sight feed and splash feed systems are found to be inadequate to take care of all the bearing points with any degree of reliability. In such engines a more positive lubrication is provided for by the mechanical or **forced feed** system.

This involves the use of a special oil tank from which the oil is forced by one or more mechanically driven pumps into individual feed pipes which distribute the proper amount of oil to each bearing point of the engine. Such a tank is termed a **Multiple Lubricator**, and it is usually operated from the crank shaft of the engine, so that the oil supply changes with the motor speed, thus automatically regulating the rate of flow in the oil feed pipes to meet the variable demands of the motor.

After being used in the various parts of the engine, the oil is usually cooled off, strained, and then forced back into the tank, thus being circulated over and over again as long as it retains its proper lubricating qualities.

OIL STRAINERS.

In order to remove any foreign matter such as gum, dirt and steel chips from the system, a wire gauge strainer is usually placed in the suction pipe of the circulating pump located at the oil

tank. This strainer should be frequently removed and thoroughly cleaned to prevent any serious obstructions to the flow of oil due to the gumming up or collection of foreign matter at that point. It is also advisable to strain the oil before it is admitted into the supply tank, oil cups, and the oil well in the crank case. The oil at the bottom of the crank case should be periodically drained off through the drain cock provided for that purpose, and the interior should be flushed out and cleaned with kerosene oil to remove the grit and gum before the new oil supply is admitted.

NON-RETURN FORCED FEED SYSTEM.

In order to obtain an absolutely reliable and unobstructed flow of oil to the various bearing points of large motors used for racing-automobiles and for aviation, the oil is forced to these points by mechanically driven pumps at high pressure and it is then allowed to be wasted, being constantly replaced by a fresh supply from the pump. This is known as the **Non-return Forced Feed System**, and, although it is very wasteful and expensive, it has the advantage of greater simplicity and reliability, which is particularly important for aviation purposes.

OIL CUPS.

There are many varieties of oil cups used for purposes of lubrication, some being made with metal bodies, and others with glass cases having a

tube or standpipe inside the cup through which the oil drips. These are usually provided with a glass guage at the bottom, so that the rate of flow can be timed by observing the number of drops flowing per minute, and with an index arm on top of the cup, its position indicating whether the oil feed is turned on or shut off. Fig. 42 illustrates



Fig. 42

Sight Feed Oil Cup made by the Lunkenheimer Co.

such an oil cup known as the **sight-feed** type made by the Lunkenheimer Co.

In some cases a more automatic form of oil cup, known as the **Wick-feed** type, is used at points requiring a limited amount but steady lubrication. The wick oil cup is made up of a metallic case having a standpipe through which a strand of

soft wicking is threaded. The upper open end of the wick falls over the top of the standpipe, dipping into the oil, and the other looped end rests upon the surface of the bearing. The friction in the bearing generates the heat that draws the oil supply from the cup through the wicking. Since this oil supply varies with the heat in the bearing, it forms a simple automatic system of lubrication.

MULTIPLE LUBRICATORS.

Fig. 43 illustrates two common types of multiple lubricators manufactured by the Lunkenheim Co., consisting of the oil supply tank, the

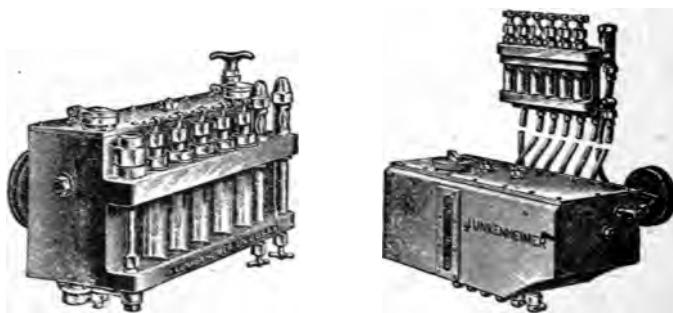


Fig. 43

Multiple Lubricators for the Forced Feed System made by the Lunkenheim Co.

circulating pump mechanism, and the feed pipes extending through the top of the tank. These oil feed pipes are provided each with a visible glass gauge to indicate the number of drops per minute

in each individual feed, and they have adjustable needle valve spindles on top to regulate the rate of flow according to the demands of the various parts of the motor.

The usual rates of lubrication allowed for the different parts of the motor are as follows:—

15 to 20 drops per minute to the crank case oilers; 8-10 drops to the cylinder; 6-8 drops to the main crank shaft bearings.

The general piping layout of a Forced Feed Lubricating system for a Four-cylinder vertical engine is shown in Fig. 44. The oil tank is shown in both front and side views. It has eight feed pipes provided with needle valves (N) and a pump driven by pulley (P) from the crank shaft. The cylinder oilers are located at C, the main crank shaft oilers are at M, and the crank case oilers at K. The fly wheel (F) is shown driven by crank shaft (S) in the usual manner; the front part of the crank case is removable, bolted together at points R. Most of the details were omitted for the sake of simplicity.

GREASE CUPS.

At points where grease is required to be fed regularly, some form of grease cup is employed. This usually consists of a metal cup provided with a plunger threaded on the outside and projecting over the top of the cup. The grease is forced

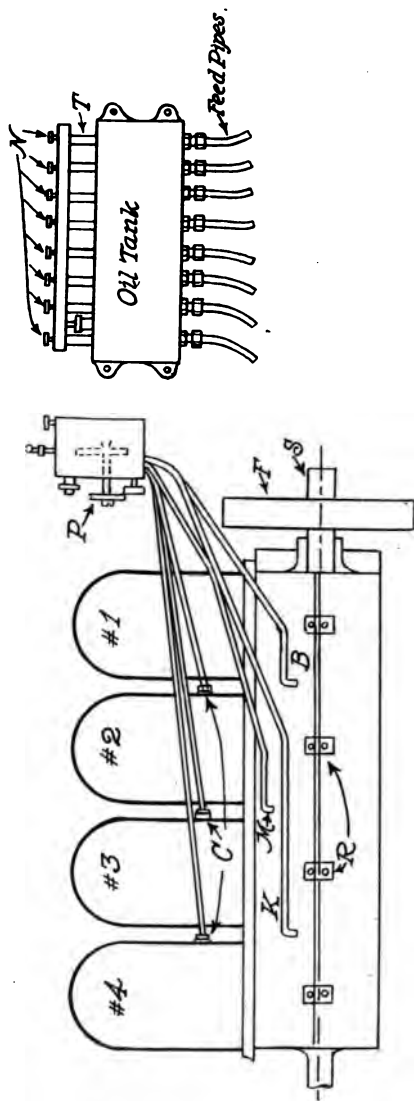


Fig 44.- The Multiple Forced Feed Lubricating System.

down to the bearing by screwing this plunger into the cup until the supply is exhausted. This requires frequent refilling especially at points where the bearing is subject to considerable speeds, in which case an automatic supply of a heavy grade of oil is much more reliable and satisfactory.

LUBRICATION TROUBLES.

An over supply of oil will often cause as much trouble as insufficient lubrication, particularly in the cylinders, where this may cause either misfiring at the spark plugs, or preignition and back firing. But, as a rule, the majority of troubles due to defects in the lubricating system are caused by the parts running dry and overheating to a dangerous point. These are usually made evident by pounding in the cylinders and noises of scraping at the bearings, often accompanied by smoky exhaust and the smell of frying oil and gum at the points affected. Any obstruction in the oil supply system will quickly develop these symptoms, giving fair warning to the operator that the bearings and piston are getting hot. If the trouble is not quickly remedied, the piston will begin to rub against the cylinder walls and finally stop by friction on account of expansion, due to the heat developed by running without lubrication. This will result in badly scratched cylinder walls, causing compression leaks and thus lowering the general efficiency of the motor. The bearings running with-

out oil will also be quickly worn out, and, in severe cases, the shafts may be seized, which stops the motor. It is therefore evident that any serious defects in the lubricating system, if neglected, will cause a considerable loss of time and money in repairs.

REMEDIES.

As in many other troublese, the maxim hold true here, that "an ounce of prevention is worth a pound of cure".

To avoid lubrication troubles, the oil should be kept clean and free from admixtures. It must be carefully regulated for each particular point and the various cups and reservoirs must be frequently inspected to be sure of a sufficient supply. The oil feed pipes should be protected so that they are not bent, punctured or squashed while the motor is running. In case the motor is stalled due to the piston running dry and getting stuck in the cylinder, it might be necessary, as a temporary measure, to open the relief cock at the top of the cylinder, after it has cooled off, and pour kerosene oil into it, turning the engine over several times by hand until the oil has sufficiently lubricated the sides of the piston to allow its free motion. The permanent damage must be remedied later by reboring the cylinder and inserting new piston rings to prevent a loss of power due to compression leaks.

QUESTIONS ON CHAPTER VI.

1. Name the physical and chemical requirements of oils suitable for lubrication of gas motors.
2. What are the advantages of the sight-feed oiling system?
3. Compare the relative merits of the splash feed and forced feed oiling systems.
4. What are the functions and principal parts of the multiple lubricator?
5. Give the proper rates of feeding oil to the following parts of a gas engine:
 - (a) The Crank Case.
 - (b) The cylinder.
 - (c) Main crank-shaft bearings.
6. What is meant by "wick-oiling"?
7. What is the advantage gained by adding graphite to the system, and the correct proportion for cylinder lubrication?
8. Enumerate the most common gas engine troubles caused by an excess of oil supply.
9. What are the results of partial or total failure in the supply of oil to the cylinder?
10. How can most lubrication troubles be avoided?
11. What is the method of procedure for starting the motor in case the piston is caught in the cylinder due to lack of oil?
12. What is the advantage in using the non-return forced-feed oiling system for aeroplane motors?

ANSWERS TO QUESTIONS ON CHAPTER V.

1. The hot-tube ignition system is simple and direct; but it is not very reliable; it is expensive in fuel and equipment, and it does not provide for close regulation.

2. The total resistance of 800 ft. of wire, having a specific resistance of 0.00025 ohms per ft. is equal to:—

$$0.00025 \times 800 = 0.2 \text{ ohms}$$

3. The current supplies to above circuit from

$$220 \text{ volt mains is equal to } \frac{220}{0.2} = 1100 \text{ amperes.}$$

The power consumed in this circuit is:—

$$220 \times 1100 = 242,000 \text{ watts} = 242 \text{ K.W. (Kilo-watts).}$$

4. Electro-magnetic induction is the process of generating electric power in a circuit by varying the strength of the magnetic field surrounding it.

5. In the make-and-break system the ignition spark is produced by breaking the circuit in the igniter and causing the current to continue its flow across the gap due to electrical inertia.

6. The circuit of the make-and-break system for a single-cylinder engine consists of a battery, or a magneto (mostly both); a primary induction coil; a switch; and the igniter with the timing mechanism.

7. In a four-cylinder single acting engine using

the jump-spark system, the following ignition equipment is required: A low-tension magneto; a battery; a double-throw switch; a commutator; timing mechanism; four induction coils with vibrators and condensers; four spark plugs.

8. The induction coil is used to raise the voltage of the ignition circuit to a value large enough to overcome the air resistance in the gap. It operates on the principle of electro-magnetic induction, the primary coil acting as the magnet, the vibrator producing the variations in magnetic strength, and the secondary coil generating the induced current at high voltage.

9. The advantages of the Edison battery are: Its light weight; reliability; freedom from fumes; strength of construction. The disadvantages are: high cost; low watt-hour efficiency; low voltage per cell.

10. The magnetic switch controls the storage-battery circuit automatically and prevents overcharging the cells or running them down too low.

11. The principal causes of failure of the ignition system are:—Moisture, corrosion, dirt, overheating, loose connections, and defective equipment.

12. To locate the misfiring cylinder, disconnect the spark-plugs, one at a time, with the engine running, and when the faulty cylinder is disconnected, this will not decrease the speed of the motor.

CHAPTER VII.

THE COOLING SYSTEM.

The thermal efficiency of any gas motor depends, theoretically, upon the range of temperatures between the combustion chamber and the exhaust pipe, since the greater the difference in temperature between these two ends of the cylinder, the greater is the quantity of heat available for useful work. According to this principle, the cylinder walls should be kept as hot as possible, since the effect of cooling them is to lower the power output of the motor. There are, however, many practical considerations limiting the allowable temperature of cylinder parts to a maximum of about 450 degrees F. At higher temperatures, the metal loses its mechanical strength; the piston and valves expand to such a degree that they cannot operate smoothly; and the lubricating oil begins to vaporize and decompose, making it impossible to keep the cylinder properly oiled.

The function of the cooling system is, therefore, to carry away the heat from the cylinder walls fast enough to keep their temperature not higher than 400 to 500 degrees F., this rate of **radiation** or heat absorption not being great enough to appreciably lower the power capacity of the motor.

GENERAL PRINCIPLES OF HEAT RADIATION.

The process of heat radiation generally consists of an interchange of heat between two substances, the total quantity of heat lost by one substance being equal to the heat gained by the other substance.

Since the quantity of heat absorbed by any body depends upon its rise in temperature, its weight, and specific heat, these factors will determine the amount of heat that can be carried away by any cooling agency during any given period of time.

The rate of radiation, therefore, depends upon the following conditions:

- (1) It increases with the size of **radiating surface**.
- (2) It decreases with the **thickness** of the communicating walls.
- (3) It increases with the **difference in temperature** between the the hot body and cooling medium.
- (4) It increases with the **specific heat** of the cooling fluid.
- (5) It increases with the **rate of circulation**.

The various types of cooling systems utilize these principles to keep the cylinder walls at the proper temperature.

AIR COOLING SYSTEM.

Air is in all cases the final agency for carrying the heat away from the cylinder to the surround-

ing space. In some cooling systems this is done indirectly, by using some liquid to circulate around the walls and then communicating this heat to the air; in the smaller sized motors, developing in each cylinder not more than five H.P., such as are used in the motor-cycle or in the small portable engines, the air is used directly as a cooling medium.

In order to increase the rate of radiation in the air cooling system, the radiating system is usually enlarged by constructing the cylinder with a number of ribs cast solid on the outside of the walls as indicated in Fig. 12 (see chap. III), which allows a much greater area of hot metal to come in contact with the air. The rate of circulation of cool air is also increased by placing near the cylinder walls a fan driven at high speed from the crank shaft, thus replacing the warm air as fast as it absorbs the heat of the engine.

Another method of cooling by air that has recently been developed in this country consists of placing a special sheet-iron housing around the cylinders, fastened to the cylinder walls by means of projecting bosses and left open at the bottom. The front of this housing has a circular enlarged space for a fan, which forces the cool air through the top of the enclosures and circulates it around the cylinders, discharging the heated air through the bottom. This provides a much larger radiating surface and it is very simple and efficient for small sized motors.

WATER JACKETS.

For motors having large cylinders which develop more than 5 H.P. each, the direct air-cooling system is not sufficient to take care of all the excess heat generated in them. In such cases the cylinders are made with double walls extending vertically about two-thirds down, also around the cylinder head, and in some cases even around the valve chamber and the exhaust piping. The spaces between the double walls, known as **Water Jackets**, are used for circulating through them some medium having a higher value of specific heat than air, such as water, oil, or special mixtures adopted for the purpose. The general construction of such water jackets is indicated in Figs. 10 and 11, (see Chap. III), where these walls are shown cast solid with the cylinders.

In some types of motors used for aviation the water jackets are built of thin copper to increase the heat-carrying capacity of the system.

WATER CIRCULATING SYSTEMS.

In systems using water or a special mixture as a cooling medium, the temperature of the liquid in the jacket should be about 160-180 degrees Fahrenheit. This is accomplished by constantly circulating the mixture, forcing the hot liquid from the jackets to a special air cooled **radiator**, and drawing the cool liquid from the radiator back to the jackets. This may be done by the

so-called natural, or **Thermo-Siphon** process, or by the more positive method of employing a circulating pump.

The thermo-siphon process is based on the principle of the action of heat upon the density of any liquid, making it lighter at higher temperatures, and thus forcing the heated portion of the mixture to the upper parts of the jackets. From there it flows to the top of the radiator where its heat is transmitted to the air, and, becoming denser, it falls by gravity to the bottom of the radiator and into the lower part of the cooling jackets, which is usually placed below the bottom of the radiator to provide a natural flow. This system has the advantage of simplicity; but it depends upon a fairly level position of the motor, which is not always the case with portable equipment; and the rate of circulation is, naturally, not fast enough to take care of very large motors.

A more positive method of circulating the liquid is by the use of some type of a circulating pump located at the inlet to the cylinder jackets, and driven from the crank shaft. The general arrangement of such a system for a four-cylinder engine is shown on Fig. 45, where the water from the circulating pump (P) is forced to the pipe (A) leading to the manifold (M), which branches off to the jackets (J) of the individual cylinders. The heated liquid passes out at the top through pipe (B) into the radiator (R), where it is cooled

and drawn into the suction pipe of the pump to be used over again in the same manner. This makes a closed system, and at ordinary operating conditions, the same amount of liquid can be circulated for a long period of time without being refilled from outside sources.

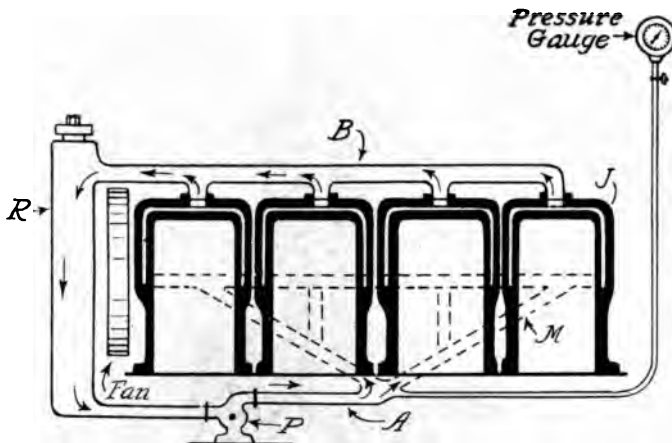


Fig. 45-Mechanically Circulated Water Cooling System

For stationary engines some form of open circulating system is often employed, making use of the absorption of heat due to vaporization in open tanks, cooling towers or cooling ponds. This is applicable only to engines having a sufficient supply of cold water, not too expensive to be used for such a purpose.

CIRCULATING PUMPS.

In the majority of stationary gas-engine installations the circulating pump for the cooling liquid is driven from the crank shaft, and is usually of the plunger type with automatic globular valves, as illustrated in Fig. 46, which shows a cross-



Fig. 46

Plunger Type Water Pump. International Harvester Co.

section through a small plunger type water pump built by the International Harvester Company.

The reciprocating movements of the plunger are produced by means of an eccentric keyed to the crank shaft. When the eccentric lifts the plunger to the top of the pump chamber, this

creates a partial vacuum in this chamber, causing a suction strong enough to lift the spherical inlet valve (ball check) and thus admitting water to the pump. At the next half revolution of the eccentric the plunger moves down, creating a water pressure which forces the inlet ball check, located at the right (See Fig. 46)to close, and the discharge ball check, at the left—to open, and allow the water to be discharged to the jackets.

These pumps are very efficient, but they require a great deal of attention, since any slight roughness in the pump cylinder or in the valve passages will materially reduce their output. They are generally not very powerful, since their rate of water delivery is intermitten, coming in short pulses depending upon the speed of the motor.

To secure more positive action for small sized gas motors, the various types of **rotary** pumps are employed. In these types the water is forced through the pump by the action of the rotating vanes or gears. This creates a vacuum at the inlet and forces the water out through the discharge pipe with considerable velocity imparted to the liquid by the rotary motion of the vanes or gear teeth.

Fig. 47 is a simplified drawing of a rotary gear pump employed on many automobile engines, one of the gears (G) being keyed to the shaft N, which is driven by other gears from the crank shaft. The inlet pipe (S) is connected to the

radiator, and the discharge pipe (D) is attached to the manifold supplying the water jackets as indicated in Fig. 45.

The rotary pump delivers a steadier stream of water than the plunger type; but its operation depends upon the action of many projecting parts

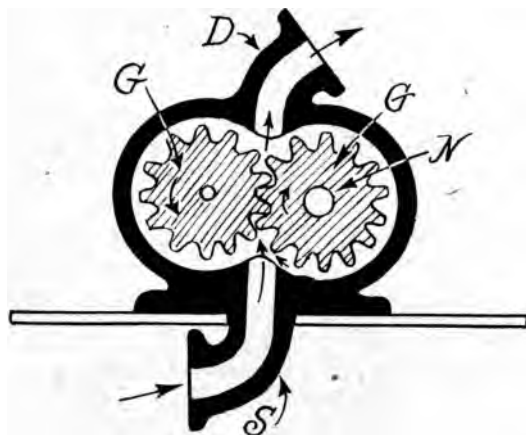


Fig. 47-Rotary Gear Pump.

which are liable to be covered with deposits of scale and grit, causing serious obstructions to the free circulation of the cooling liquid.

In many modern automobile engines the forced circulation of water is secured by means of a **centrifugal** pump, shown in Fig. 48. This pump has about three or four large curved blades (B) revolving in a light metal casing (C) and capable

of creating a very powerful circulation, providing the shaft (N) is driven at high speed. The water is drawn by suction through the inlet pipe (S),

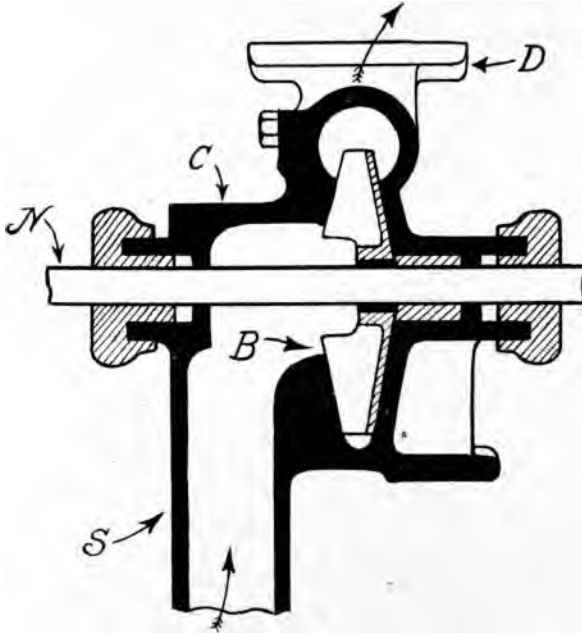


Fig. 48-Centrifugal Pump

and is forced out to the jackets through a large sized discharge pipe (D), in a continuous stream.

The action of this pump is based on the principle of **centrifugal force**, which is developed in

any revolving body due to the resistance of its particles to circular motion. This force tends to throw the outside particles of the revolving mass away from the center of motion in a straight line tangent to the edge of the circle, in the same manner as mud is thrown off the rim of a revolving wheel. In the pump this forces the particles of water along the curved paths of the revolving blades until they find an outlet through the discharge pipe. The vacuum created at the center of these blades develops the suction which draws the water from the inlet pipe.

RADIATORS.

Since the final dissipation of heat from the cylinders to the air takes place in the radiator, its radiating surface is made as large as practicable, consistent with mechanical strength and freedom from friction to the flow of the cooling liquid. Usually the radiator is made up of a number of circular pipes or tubes, arranged in some compact manner and having a large number of small circular or rectangular metal disks attached to them at regular intervals, to increase the radiating surface. For a motor using the thermo-siphon system the amount of radiating surface should be at least 5 sq. ft. per rated H.P. With a forced circulating system the radiating surface is reduced, in order to prevent the trouble of cooling the cylinders too fast and thus decreasing the efficiency of the motor.

Fig. 49 illustrates two common types of radiators combined with water tanks, for use in automobiles. The radiator shown at (a) is made up of a series of horizontal tubes with radiating disks,

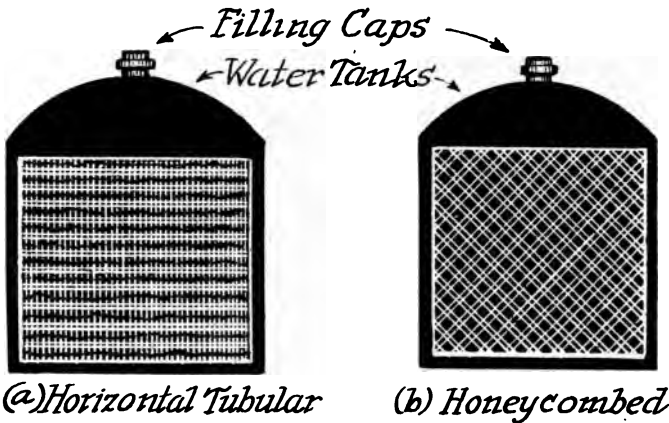


Fig. 49~Radiators

while at (b) is shown a type of radiator having a cellular or honeycombed construction, which results in a larger radiating surface per cubic ft. but which offers a greater obstruction to the circulation of the liquid. This latter type is, therefore, preferable for use in connection with a circulating pump.

FANS.

In many radiating systems, whether air cooled or water cooled, the circulation of air is increased by the use of a fan mechanically driven from the

main shaft of the motor at about $1\frac{1}{2}$ times to twice the speed of the crank shaft. These fans are usually made up of a number of vanes inclined at an angle to create a suction, driving the heated air away from the cylinders or the radiator and displacing it with cooler air from the surrounding space. Fig. 50 is a simplified draw-

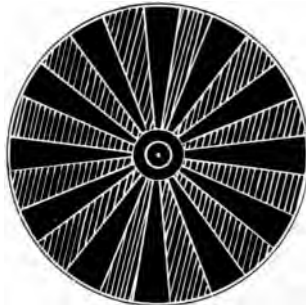


Fig. 50-Cooling Fan

ing of a cooling fan designed for use in automobile motors, usually driven by a belt from the crank shaft. In some motors the fan is combined with the fly-wheel by constructing the wheel spokes in the shape of thin vanes inclined at the proper angle.

For very powerful motors, several fans or even large blowers have to be used to provide the proper circulation of air, especially in stationary gas engines where the cooling process is not aided by the motion of the machine.

In aviation motors the function of the fan is

often performed by the propeller and also by the cooling effect of the air.

NON-FREEZING MIXTURES.

The objection to using water as a cooling medium is due to the fact, that when freezing it expands materially, which is liable to ruin the cylinders or the radiator by bursting the jackets or pipes, if proper measures are not taken to prevent such freezing: either by draining the system after the motor is stopped; by protecting the motor from the effects of the cold weather; or by using some special non-freezing mixture.

A very common mixture used to prevent the freezing of water is made up of a 50% solution of calcium chloride, which will lower the freezing point to about — 15°F.

For use in automobile engines this solution is prepared by first dissolving 15 lbs. of the salt in one gallon of water. This gives about 2 gallons of the saturated solution at 60°F., to which 2 or 3 gallons of water should be added to dilute it to a 50% solution. A small quantity of slaked lime is also added to neutralize the action of this mixture as an acid.

In using the calcium chloride solution care must be taken to provide a proper supply of water to make up for its evaporation so as to prevent crystallization of the mixture when it reaches the point of saturation; its temperature should also be kept

below boiling to avoid the formation of hydrochloric acid, which is very injurious to the metal. The specific gravity of the proper 50% solution is 1.21, which could be tested by the hydrometer to ascertain whether we have a sufficient supply of water in the mixture. In some mixtures Potassium Carbonate is used on account of its weaker acidity, but it is more expensive.

Another common anti-freezing mixture is made up of two parts of glycerine, one part of water and one part of wood alcohol, which reduces the freezing point to zero F. The objection to glycerine is that it attacks the rubber in the gaskets and packing, and it fouls the system unless renewed very frequently.

In cases where the cooling system is absolutely closed and free from evaporation troubles, a solution containing from 25% to 40% of denatured grain alcohol is used with the addition of some glycerine and slacked lime. This lowers the freezing point to about -3°F . with 25% of alcohol, and to about -25°F with a solution containing at least 40% of alcohol.

In preparing these anti-freezing mixtures, the strength of the solution must also be governed by the danger from **Electrolytic action**, or the corrosive action due to the solution forming a chemical combination with the metals in the jackets and radiator, and generating an electric current, in the same manner as in an ordinary primary cell.

With a salt solution, this electrolytic action is very prominent, while the alcohol solutions are much more satisfactory in that respect.

PIPING.

The rate of circulation is often seriously impeded by friction in the piping system and in the radiator tubes or cells. This must be properly allowed for in the design of any practical cooling system, by computing the total **loss of flow** due to piping. The actual values of friction loss in pipes of various sizes, in systems delivering from 5 to 500 gallons per minute, are given in Table No. 4, which was compiled by Mr. G. A. Ellis for the Warren Steam Pump Co.

TROUBLES DUE TO IMPROPER COOLING.

The direct results of a defective cooling system are: **Poor lubrication** with all its attendant cylinder and bearing troubles; and also **preignition**, due to the mixture reaching its ignition temperature during the earlier part of the compression stroke, before the engine is ready for the explosion.

Defects in the cooling system are caused either by some obstruction in the path of flow due to crystallization of the mixture, scale deposits and metal deposits due to chemical and electrical action; or circulation troubles may be caused by obstructions and breaks in the piping system; also by a defective pump, radiator or cooling fan; and, finally, by freezing of the liquid.

Friction Loss in Pounds Pressure Per Square Inch.

For each 100 Feet of Length in Different Size Clean Iron Pipes, Discharging Given Quantities of Water per Minute.
Also Velocity of Flow in Pipes, in Feet per Second.

G. A. ELLIS, C.E.

Discharged per Minute.	1/2 Inch.	3/4 Inch.	1 Inch.	1 1/4 Inch.	1 1/2 Inch.	2 Inch.	2 1/2 Inch.	3 Inch.	4 Inch.	6 Inch.	Discharged per Minute.
5	8.17	24.6	3.63	3.3	2.04	0.84	1.31	0.31	0.91	0.12	5
10	16.3	49.2	7.25	6.6	4.08	1.68	2.61	0.62	1.82	0.24	10
15			10.9	9.9	6.13	2.52	3.92	0.93	2.73	0.36	15
20			14.5	13.2	8.17	3.36	5.22	1.24	3.63	0.48	20
25			18.1	16.5	10.2	4.20	6.53	1.55	4.54	0.60	25
30					12.3	5.04	7.84	1.86	5.45	0.72	30
35					14.3	5.88	9.14	2.17	6.36	0.84	35
40					16.3	6.72	10.4	2.48	7.27	0.96	40
45							11.7	2.79	8.18	1.08	45
50							13.1	3.10	9.09	1.20	50
75							19.6	4.65	13.6	1.80	75
100								6.18	18.2	2.40	100
125								7.42	22.4	2.88	125
150								8.66	26.6	3.36	150
175								9.90	30.8	3.84	175
200								11.14	35.0	4.32	200
250								13.9	44.2	5.54	250
300								16.7	53.4	6.76	300
350								19.5	62.6	7.98	350
400								22.3	71.8	9.20	400
450								25.1	81.0	10.42	450
500								27.9	90.2	11.64	500

Table No. 4.-Compiled by G.A. Ellis, C.E.
for the Warren Steam Pump Co.

In some cases the cooling system is **too perfect**, i. e., it cools the cylinders so fast that the engine cannot develop its full power, especially on starting the motor. This retards the rise in speed and lowers the general efficiency of the engine.

REMEDIES.

The deposit of lime or of any other scale upon the interior walls of the cooling system can be removed by filling the entire space with a 5% solution of hydrochloric acid and leaving it there for a period of about 10 to 12 hours, after which the acid should be drained off and the piping thoroughly flushed with running water.

The non-freezing mixture must be carefully prepared to avoid any chemical or electrolytic action and to secure as low a freezing point as possible under the circumstances.

In draining the system to prevent bursting of the pipes or jackets due to freezing, great care must be taken to see that no liquid is left in any pockets or chambers; and the pump should be operated for a few minutes after the liquid is drained off to remove any liquid remaining in the pump chamber or in any other part of the system.

QUESTIONS ON CHAPTER VII.

1. Enumerate all the conditions affecting the rate of heat radiation.
2. How does the cooling of cylinder walls affect the efficiency of the motor?

3. What are the practical limitations in temperature of the cylinder walls of a modern gas motor?

4. What equipment is required for an air-cooling system of a two-cylinder motor-cycle engine?

5. What equipment is required for a water cooling system of a six-cylinder motor developing 50 H.P. and using forced circulation?

6. What are the advantages and disadvantages of the plunger type of circulating pump?

7. What is the principle of operation of the centrifugal circulating pump?

8. How much radiating surface is required for a cooling system of a four-cylinder motor developing 40 H.P. and using the thermo-siphon system of circulation?

9. What is the advantage of using a 50% solution of calcium chloride as a cooling liquid?

10. How does the addition of slaked lime affect the qualities of the cooling mixture?

11. How is the operation of the gas motor affected by the failure of the cooling system?

12. How can the scale deposit be removed from the water circulating system?

ANSWERS TO QUESTIONS ON CHAPTER VI.

1. Lubricating oils for gas motors should have the following properties: Viscosity; fluidity; freedom from acids; freedom from decomposition be-

low 500°F; high flash point; high burning point (about 600°F); a low coefficient of friction; physical and chemical purity.

2. The sight-feed oiling system is simple, direct and economical.

3. The splash-feed oiling system is simple and reliable, but it is wasteful of oil; the forced feed oiling system is more positive and efficient, but it requires careful handling, also frequent inspection and repairs.

4. The multiple lubricator acts as the supply tank for the system and regulates the flow of oil to the various bearing points in the motor. It consists of a mechanically driven pump or a series of pumps, an oil tank, a number of feed pipes with glass gauges for indicating the rate of flow, and set screws with needle-valve spindles to regulate this flow according to the requirements of each oiler.

5. The rates of feeding oil to the various parts of the motor are as follows:

(a) To the crank case—15 to 20 drops per minute.

(b) To the cylinder—8 to 10 drops per minute.

(c) To the main crank-shaft bearing—6 to 8 drops per minute.

6. Wick-oiling is a method of lubrication by means of a wick placed in the oil cup, with one end resting upon the bearing surface, and automat-

ically drawing the oil through the wick due to the heat generated in the bearing.

7. The addition of graphite to the oil raises its viscosity without making it less fluid. It should be used in the proportion of about one teaspoonful of graphite to a pint of oil.

8. An excess of oil supply may insulate the gap at the spark plug and thus cause misfiring; or it may enrich the explosive mixture sufficiently to cause preignition and back-firing.

9. A failure in the supply of oil to any part of the motor causes over-heating at the bearing surfaces. This results in expansion of the working parts, causing pounding and scraping, often ending with the stopping of the motor and permanent injury to the cylinder walls.

10. Lubrication troubles can be avoided by using proper oil, keeping the system clean and frequently inspected, and, finally, by protecting the piping and equipment from mechanical injury.

11. To start the motor with the piston caught in the cylinder, cool off the engine, then open the relief cock and lubricate the cylinder with kerosene oil by turning the engine over by hand.

12. The non-return forced feed oiling system is the most positive method of lubrication, since it is free from all danger of obstructions. It is wasteful in oil; but this system is justified for use in aviation motors on account of its simplicity and reliability.

END PART ONE.

PART II

PRACTICAL APPLICATIONS.

CHAPTER VIII.

THE STATIONARY GAS MOTOR.

The development of gas power on a large scale involves more careful regulation of fuel supply and closer speed and ignition control than is required in operating smaller sized motors. This is due to the fact that with large stationary gas engines the question of economy is of greater importance on account of the large saving in fuel that can be obtained with even a slight increase in the working efficiency of the engine. The cooling system of larger units is also more elaborate than in small gas motors, since the larger volumes of fuels and the higher temperatures of explosion used in stationary gas engines result in much greater heating of their cylinder walls, inlet and exhaust valves, and exhaust piping.

The most common fuels used in the larger sizes of stationary gas engines are the products of anthracite and bituminous coal in the form of **producer gas**, **illuminating gas** or **blast-furnace gas**.

The use of **natural gas** is limited to the particular localities where such fuel can be obtained in suffi-

cient quantities for power development. Many stationary gas motors employ the heavier **petroleum oils** in liquid form by injecting them into the cylinders under pressure. The use of the lighter petroleum products, such as **gasoline**, is better adapted for the smaller sized motors on account of its limited supply and prohibitive cost.

GAS PRODUCERS.

The vaporization of either anthracite or bituminous coal for use in gas engines takes place in the **Gas Producer**, where the coal is burned and combined with water vapor, forming a mixture of carbon monoxide gas, hydrogen, and other hydro-carbons diluted with nitrogen. One pound of coal usually produces about 80 cubic ft. of gas, having a calorific value of from 140 to 160 B.T.U. per cu. ft. This gives the maximum heating value of 12,800 B.T.U. obtainable from each pound of coal, as against the theoretical heating value of coal equal to 19,000 B.T.U. per lb. The maximum thermal efficiency of the gas producer is therefore equal to:

$$\frac{12800}{19000} = 67.4\%.$$

The advantage gained is the generation of a gas fuel from coal which could not be used in solid form for developing power in the internal combustion engine.

The general arrangement of a typical gas-producer plant is shown in Fig. 51, which represents the

suction type of producer, where the circulation of gas takes place due to the suction from the engine cylinders, while in the **pressure** type of producer the gases are circulated by means of a large power-driven blower, independent of the operation of the engine. Referring to Fig. 51, the coal is fed through hopper (H) to the gas **generator** (G), which consists of a vertical cylinder lined with fire-brick, and is provided with ash and air doors and with a large grate where the coal undergoes complete combustion. This results in the production of carbon dioxide gas, which in passing upward through the large mass of coal, picks up more carbon, partly combining with it chemically to form carbon monoxide, a combustible gas. These hot gases pass through pipe (a) to the **vaporizer** (V), where they come in contact with a series of vertical water tubes supplied with hot water from the engine jackets. This readily generates steam which is drawn through pipe (b) into the space under the generator grate, mingling with the air and being decomposed by the intense heat at the bottom of the generator into oxygen and hydrogen. The oxygen helps combustion, and the hydrogen is set free, forming a mixture with the carbon dioxide, carbon monoxide and nitrogen liberated by the air.

This combined product is now passed through pipe (c) to the **Scrubber** or **purifier** (S), where the gases are forced through a deep bed of coke over which water is constantly sprayed. This removes most of

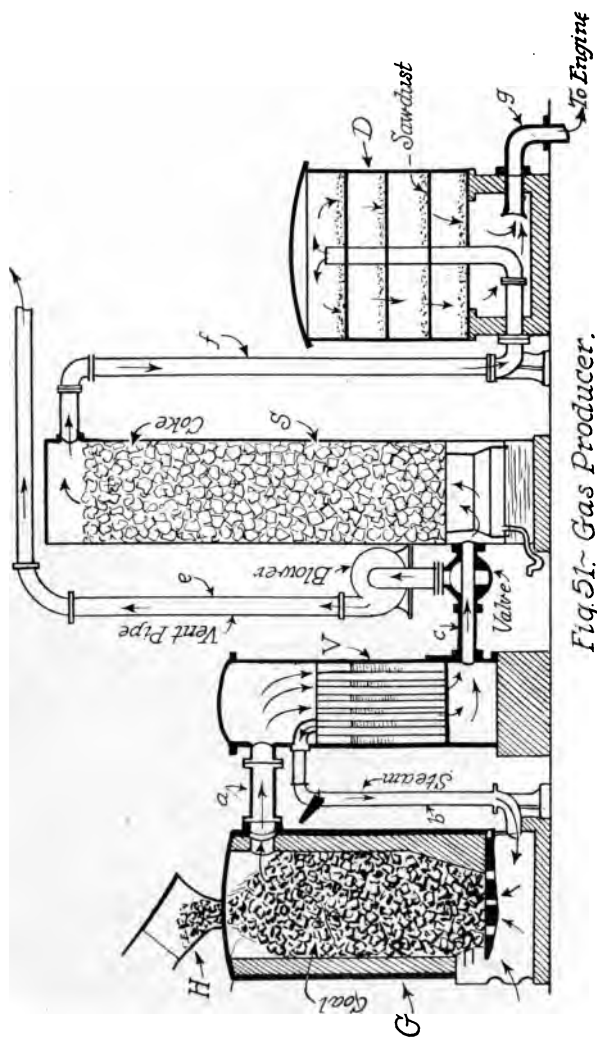


Fig. 51. Gas Producer.

the dust, ashes and other impurities and cools the gas. From the purifier the gas passes through pipe (f) to the saw-dust drier (D) which removes the tarry products and excess moisture, leaving the fuel in proper condition for use in the engine, where it is drawn by suction through pipe (g).

In starting the suction type of gas-producer, the valve located in pipe (c) leading to the scrubber is closed, and suction is provided by means of a small hand-blower connected to vent-pipe (e), allowing the fresh gas to escape until it attains the proper composition and qualities required for use in the engine. Then the blower is stopped and connection is made to the engine as described above.

The average composition of producer gas, by volume, is as follows:

Carbon Monoxide.....	27%
Carbon Dioxide.....	2%
Hydrogen	12%
Methane, or Marsh Gas.....	2%
Nitrogen	57%

The carbon dioxide gas and the nitrogen have no heating value, since they do not combine with oxygen when the combustion takes place in the engine.

NATURAL GAS.

In localities where petroleum oils are abundant, there is frequently found a large supply of natural gas which flows from the ground with considerable force, and which can be utilized for developing

power by piping it through a pressure-reducing valve to an engine adapted for operating with this fuel. This gas consists of about 90% of methane or marsh-gas, and about 1% to 10% of hydrogen, the balance being made up of traces (very small quantities) of carbon monoxide, carbon dioxide, and other hydro-carbons mixed with oxygen and nitrogen. On account of its large percentage of rich fuels this gas has a much higher calorific value (about 800 to 1100 B.T.U. per cu. ft.) than producer gas, but since it requires a correspondingly larger volume of air for its complete combustion, the thermal efficiency of its mixture with air is only about 50% greater as compared with a mixture using producer gas.

ILLUMINATING GAS.

The gas now generally used for illuminating, heating and cooking purposes can be used also for developing power, since it contains many of the constituents present in the producer gas and natural gas. It is not used for power on a very extensive scale on account of its present high manufacturing cost. But the recent development of more efficient methods for its production and the wider commercial utilization of its various by-products are gradually lowering the cost of illuminating gas, making it more available for use as a fuel in internal combustion engines.

There are two principal methods of manufacturing illuminating gas: (1) By heating coal in sealed

STATIONARY GAS MOTOR 195

retorts without any supply of air or moisture, the product being known as **coal gas**, which is drawn from these retorts by means of a special pump, after which it is purified. (2) By heating coal or coke to incandescence, and then bringing it in contact with steam, which is decomposed by the heat into hydrogen and oxygen. This gas is called **water gas** and it is usually mixed with oil gas or **carbureted** to make it more luminous.

The average composition (by volume) of these two gases is as follows:

	Coal Gas (Percentage)	Carbureted Water Gas (Percentage)
Carbon Monoxide	10	28
Carbon Dioxide	3	3
Methane	31	20
Hydrogen	46	31
Nitrogen	5	3
Oxygen	0.3	0.4

One pound of coal usually produces about 30 cubic feet of uncarbureted water gas having a heating value of about 300 B.T.U. per cu. ft. By adding about 5 gallons of oil for every 1000 cu. ft. of gas, we obtain the **carbureted** water gas with a heating value of from 500 to 650 B.T.U. per cu. ft. (See Table No. 1, Chapter I.)

BLAST-FURNACE GAS.

The gas products of blast furnaces used for reduction of iron ore are very poor in hydro-carbons and contain a great deal of foreign matter which must be carefully removed before these gases can be utilized as fuel in developing power. Their use for driving gas motors is justified only by the fact that these gases represent a total loss if allowed to escape through the stack, and they can be used to advantage, as long as the cost of purifying them is not greater than the value of power developed in the engines by their use. This makes it particularly adapted for plants connected with large metallurgical processes.

OILS AND DISTILLATES

The utilization of the heavier petroleum oils and distillates for power development in large stationary gas motors requires special equipment for feeding them into the cylinders. In many engines these liquid fuels are preheated and vaporized in separate containers without mixing them with air until they are admitted into the inlet valve of the engine. In some stationary motors these liquid fuels are sprayed or **injected** directly into the cylinders at the end of the compression stroke, when the air required for combustion is under high pressure and has developed sufficient heat by its compression to burn the fuel as fast as it is injected, without requiring

any outside agency for its ignition. This method is employed in the **Diesel motor** which is now used in many power plants, pumping stations and on the latest types of the Zeppelin airships.

The calorific values and other physical properties of petroleum products are given in Table No. 2 (See Chapter II) where we find that even the cheaper distillates and crude oils have high heating values compared with the products of coal, which makes them very efficient for use in internal combustion motors.

RATING OF STATIONARY GAS ENGINES.

The power developed in any stationary gas motor depends upon the following conditions:

- (1) Size of Cylinders (bore and stroke).
- (2) Average speed of motor (r.p.m.).
- (3) Quality of fuel and mixture used.
- (4) Type of engine (horizontal or vertical).
- (5) Number and arrangement of cylinders.
- (6) Method of operation (Two-cycle or Four-cycle, Single or Double acting, etc.).

In general, the horse-power per working cylinder end, delivered at the brake of any gas motor varies directly as the square of its cylinder bore multiplied by the length of stroke and by its revolutions per minute. (For fuller explanation see **Rating** in Chapter I, also questions and answers Nos. 7 and 8, Chapter I).

This general relation can be expressed as follows:

$$P = D^2 \times S \times R \times A - B \dots \dots \dots (1)$$

Where P is the brake horse-power per working cylinder end, D is the diameter of cylinder bore in inches, S is the length of stroke in inches, R is the average number of revolutions per minute, and A and B are special numbers depending upon the various conditions given above. The values of A and B in the above formula have been found from actual power rating of numerous stationary gas engines, to be as follows:

For engines using **producer gas**, single-acting, either horizontal or vertical:

$$A = \frac{1}{17,900} \text{ and } B = -1.0 \dots \dots \dots (2)$$

For engines using **producer gas**, double acting, horizontal:

$$A = \frac{1}{20,600} \text{ and } B = -4.0 \dots \dots \dots (3)$$

For all engines using **natural gas**:

$$A = \frac{1}{15,200}; B = -5.0 \dots \dots \dots (4)$$

For single acting engines using **illuminating gas**:

$$A = \frac{1}{15,700}; B = -2.0 \dots \dots \dots (5)$$

STATIONARY GAS MOTOR 199

For horizontal, double-acting engines using **blast furnace gas**:

$$A = \frac{1}{21,000}; B = \frac{1}{5.0} \dots \dots \dots (6)$$

For all single acting engines using crude **oils or distillates**:

$$A = \frac{1}{21,875}; B = \frac{1}{0.75} \dots \dots \dots (7)$$

Finally, for all single acting stationary engines using **gasoline**:

$$A = \frac{1}{16,400}; B = \frac{1}{0.50} \dots \dots \dots (8)$$

The above values of A and B can be substituted in formula (1) to compute the HP. per working cylinder end of any particular type of engine.

Thus, in a two-cylinder, double-acting engine, using natural gas as a fuel, and having a 10-inch bore, a 12-inch stroke, and running at an average speed of 600 revolutions per minute, the brake horsepower per cylinder end is equal to:

$$\frac{10 \times 10 \times 12 \times 600}{15,200} \times 5 = \frac{720,000}{15,200} \times 5 = 42.4 \text{ HP.}$$

Since in a two-cylinder, double-acting engine there are four working ends, the total HP. delivered at the brake of this motor is:

$$42.4 \times 4 = 169.6, \text{ or about } \mathbf{170 \text{ HP.}}$$

THERMAL EFFICIENCIES.

The ratio between the mechanical power delivered at the brake of any gas engine and the heat value contained in the fuel is known as its **thermal efficiency**.

The average values of thermal efficiencies (at the brake) of various stationary gas motors are as follows:

In engines using producer, natural, or illuminating gas, they are from 18% for a 10 HP. motor to 27% for a 120 HP. motor.

For engines using blast-furnace gas, the efficiencies run from 23% to 25%. For kerosene oil engines—from 16% to 18%, and for gasoline engines—from 16% to 20%.

In the modern Diesel engine, using crude oil for fuel, the thermal efficiencies run up to about 28% in motors of 150 HP. capacity. This represents at present the highest point in the development of the gas motor.

The details of construction of the stationary gas engine depend primarily upon the number and relative position of its cylinders.

ARRANGEMENT OF CYLINDERS.

Usually when the number of cylinders is greater than two, the engine is built vertically, to economize in space that would be required for a horizontal multiple cylinder arrangement. With two cylinders,

the arrangement is, in most cases, horizontal, having them arranged either in **tandem**, **duplex**, or **horizontally opposed**. (See Fig. 18, 19 and 20, Chapter IV.)

The advantage of the tandem arrangement is the saving in engine parts and bearings, and the consequent reduction in friction, giving a higher mechanical efficiency.

Where conditions of floor space demand it, the **duplex** or **twin** arrangement is used, requiring a space of more nearly equal dimensions, while the tandem engine uses a long and narrow space. The duplex arrangement has also the advantage of more symmetrical connection to the crank shaft.

The horizontally-opposed type of motor delivers a more balanced form of power than any other horizontal cylinder engine, and it is particularly well adapted for generating electric power.

GOVERNOR.

Large stationary gas motors usually operate at constant speed, since the mechanical power developed in such engines is frequently used for driving mill machinery, water pumps, or electric generators. In order to maintain their speed nearly constant, some type of governor is employed, operating on the following principles:

(1) Regulation of fuel valve by the **hit or miss** method, which consists of automatically shutting off

the fuel supply during one or more cycles, in case the motor speed is suddenly increased.

(2) Regulation of main exhaust valve, by the **hit or miss** method, providing an idle cycle when the speed exceeds its normal value, either by automatically keeping the exhaust valve open during admission stroke, or by keeping it closed during exhaust stroke. In both cases the explosions are missed until the speed becomes normal.

(3) Regulation of the mixing valve, using the **throttling** method, by varying the amount of valve opening according to the demands of the mechanical load on the motor.

(4) Regulation of the **amount of lift** of inlet valve, thus automatically varying the quantity of mixture admitted to the cylinder. This is a modification of the throttling method.

(5) Regulation of **time of ignition**, not very common with large stationary engines, on account of the low thermal efficiency produced by this method of governing.

The hit-or-miss method of governing is more efficient, since it provides for operation at maximum compression, but it has the objection of delivering unbalanced power. The throttling method is more wasteful of fuel, but it provides a power impulse for every cycle of the cylinder.

The mechanism for governing speed in some gas motors operates by means of the effect of variation in speed upon the **centrifugal force** of the rotating

parts in either the **flyball**, or **fly-wheel** type of governor.

In the **flyball** governor, the rise in speed creates a larger centrifugal force in the rotating balls, which are attached by levers to a sleeve riding on the spindle of the governor. This spreads them farther apart, and their motion is transmitted through links to the proper valve, which reduces the speed of the motor.

In the **fly-wheel** type of governor, two heavy weights are held in place by springs near the circumference of the flywheel until a sudden rise in speed throws them farther apart, operating the valve and cutting down the speed to normal.

Some types of governor are operated on the principle of the effect of speed variation upon the **inertia** of the heavy mass of the governor. To this class belong the various **vibrating** and **pendulum** governors, in which any great rise in speed above normal actuates a lever connected to the valve-operating mechanism, throwing it out of contact with the lifting cam of the valve and thus keeping it closed until the speed is reduced to normal. In some modern gas motors the speed is regulated by means of a **hydraulic governor**, which operates by means of water pressure in the cylinder jackets. It consists mainly of a flexible diaphragm, placed between the cooling jackets and the governor mechanism which operates either the inlet, or exhaust valve. Any appreciable rise in speed automatically increases the circulation

of cooling water in the jacket, which action exerts a greater water pressure upon the diaphragm. This pressure moves the levers operating the proper valve, and thus automatically cuts down the speed of the motor. In case the speed falls below normal, the reverse process takes place.

All the above types of governor are provided with adjusting springs for predetermining the exact limits of speed control for any condition of operation.

LAY SHAFT.

The valves in stationary gas engines are usually all mechanically operated by cams or eccentrics, located on the **lay shaft**, which is driven from the crank shaft at half speed and placed, in horizontal engines, parallel to the cylinder bores. This shaft usually also operates the igniter timing mechanism and the governor, by means of proper gears, cams, or pulleys. In two-cycle engines the lay shaft is driven at full speed of the motor.

COOLING SYSTEM.

Since large stationary gas engines are usually housed in power plants, there is no objection to their use of pure water as a cooling medium. In many instances where water supply is very cheap, the engine is cooled directly from the supply mains, allowing the hot water from the jackets to escape, and doing away entirely with all radiating equip-

ment. Where this is not practicable, some means are provided for radiating the heat, such as by the use of cooling tanks, towers or ponds, the cooled water being used over again by means of a circulating pump. On account of the excessive heating of valves and exhaust piping in large gas engines, the valve chambers and exhaust pipes are frequently surrounded with water jackets connected to the cooling system; in some cases, either the exhaust valve, or both valves, are made with hollow stems and bodies, through which the cooling water is circulated under pressure.

SCAVENGING.

On account of the greater volumes of gas mixture used in large-sized engines, some provision must be made to remove the burned gases quickly from the cylinder, in order to allow the fresh charge to enter the combustion chamber freely and without mingling with the products of combustion. This is accomplished in some motors by providing a series of auxiliary exhaust ports, which are uncovered by the travel of the piston before the main exhaust valve is opened.

A more positive method of quickly removing exhaust gases from the cylinder is by **scavenging** or forcing the burned gases out of the clearance space at the end of exhaust stroke, by keeping the exhaust valve open while the piston is almost stationary, with the crank shaft at dead center, and admitting fresh

air under pressure either through the air inlet valve or a special air pump provided for that purpose. This increases the effective volume of the combustion chamber and the rate of flame propagation, which raises the power output and the thermal efficiency of the motor.

The advantage gained by using a scavenging instead of non-scavenging engine, was demonstrated in the Crossley four-cycle motor built in England, where a gain of 20% per brake horse-power was obtained by employing this method.

THE INTERNATIONAL HARVESTER ENGINE.

The practical application of the stationary type of gas motor to small isolated power plants is illustrated in Fig. 52, which shows the "Titan" engine built by the International Harvester Company. This is a horizontal four-cycle single cylinder engine adapted for burning kerosene oil. Its speed is regulated by the centrifugal type of governor operating on the hit-or-miss principle, by holding the exhaust valve open to provide for an idle cycle in case the speed rises above normal. The ignition system is of the make-and-break type, the igniter mechanism being operated by an eccentric keyed to the cam shaft, which is driven from the crank shaft by spur gears at half speed.

Since in a single cylinder four cycle motor the crank shaft receives only one power impulse for every two revolutions or four strokes, this engine

requires a flywheel mass heavy enough to provide sufficient inertia for driving the motor during the three idle strokes of the piston. This is accomplished in the "Titan" engine by providing two flywheels, placed symmetrically at the two ends of the crank shaft, as shown in Fig. 52.



Fig. 52

Horizontal Oil Engine "Titan"
Built by the International Harvester Co.

This type of engine is frequently used on portable units for driving small pumps, agricultural or lumber machinery, etc. Such detachable gas-motor units are usually provided with some special carbureting device for adapting them to burning of either crude oil, kerosene oil or gasoline.

FAIRBANKS-MORSE VERTICAL ENGINES.

Fig. 53 is a cross section through the center line of the cylinder of a vertical four-cycle single-cylinder Fairbanks-Morse engine used for small stationary gas power plants. It has an automatic inlet valve provided with a locking device for regulating the size of valve opening. The exhaust valve is operated mechanically by means of a rocker arm through the exhaust rod, roller and cam, which is fastened to the cam shaft. The governor is of the **inertia** or **vibrating** type consisting of a weight attached by a lever to the cam shaft and regulated by means of the governor spring in such a manner that any variation from normal speed affects the action of the valves, which tends to bring the speed back to the predetermined value.

The lubricating system of the small sized Fairbanks-Morse vertical engine is of the splash-feed type, consisting of an oil reservoir at the bottom of the crank case, this lubrication being distributed through the main parts of the engine by bolting to the crank pin a bent plate, known as the **oil splasher**, which dips in the oil at every revolution of the crank shaft.

The larger sizes of vertical gas engines built by the Fairbanks-Morse Company have both, the inlet and exhaust valve, mechanically operated from the cam shaft located inside the crank case, as indicated in Fig. 54. This figure is a general view of a vertical three-cylinder four-cycle engine of that type,

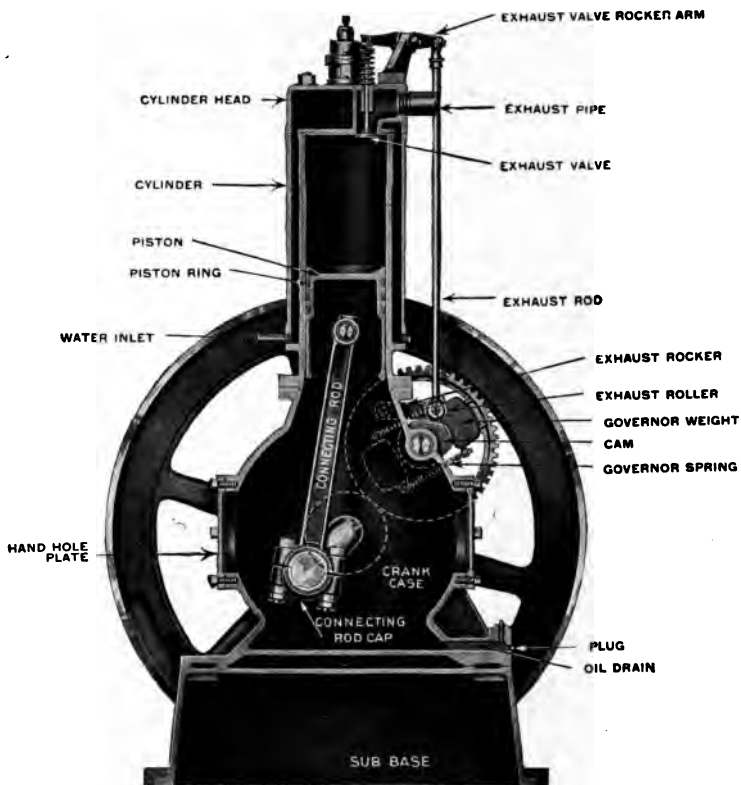


Fig. 53

Section through Vertical Fairbanks-Morse Engine

with the front plate of the crank case removed to show the cam shafts, cams, and rollers, controlling the six valves of the engine. The inlet valves are located in the cylinder heads and are operated by means of tappet arms and long rods lifted by cams. The exhaust valves are located at the sides of the cylinders and are actuated by means of push rods, cam levers, rollers and cams. The cylinders and all the inlet and exhaust gas passages are completely surrounded with water jackets, and the crank shaft is provided with two flywheels to insure an even distribution of power and a uniform speed.

THE NASH ENGINE.

In the Nash Vertical Gas Engine, built by the National Meter Company, both the inlet and exhaust valve are located at the sides of the cylinders, and they are made identical in their construction and method of operation in order to render them interchangeable, which is an important advantage with large engines, where spare parts have to be provided for cases of emergency. In this engine the cam shaft is located outside of the crank case to provide for facility of adjustment and repairs.

ELYRIA STATIONARY HORIZONTAL ENGINES.

A typical arrangement of cylinders and valves in a horizontal gas engine of medium size is illustrated in Fig. 55, which is a longitudinal section of the two-

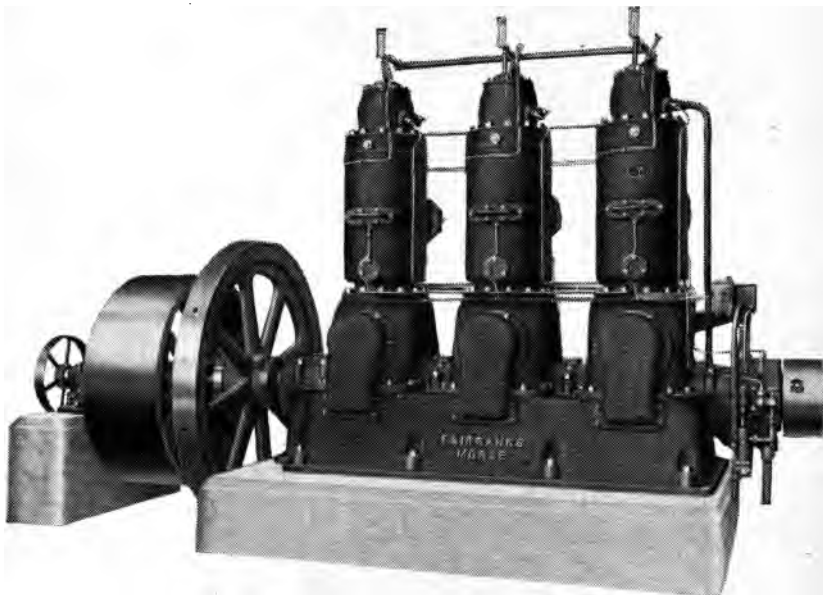


Fig. 54
Fairbanks-Morse Type "R" Vertical Engine

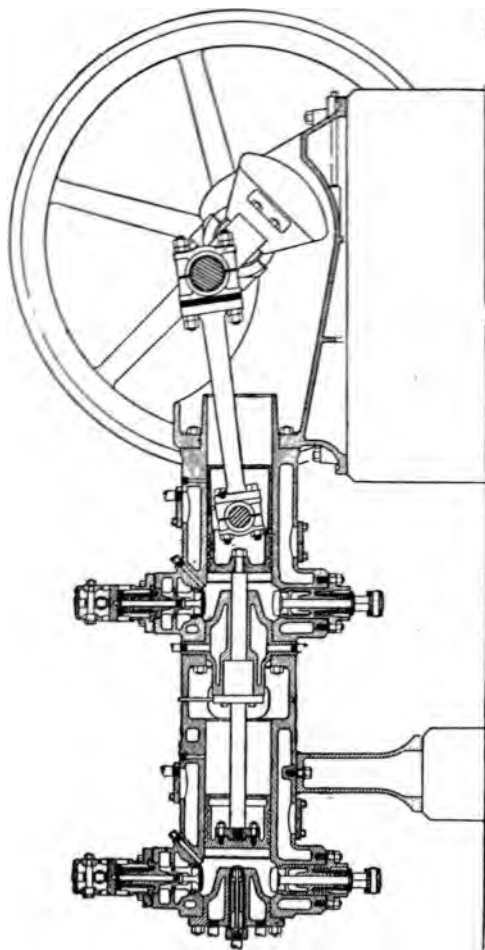


*Fig. 55.
Longitudinal Section through Horizontal
Tandem Engine built by the Elyria Gas Power Co.*

cylinder horizontal tandem engine built by the Elyria Gas Power Company. In this engine the inlet valves are located vertically above the cylinders, and the exhaust valves are placed below the cylinders and directly opposite the inlet valves.

The general arrangement of valve controlling mechanism in the Elyria gas engine is shown in Fig. 56, which is a cross-section of the same engine taken through the middle of one of the cylinders. The inlet valve is made up of two separate disks attached to the same valve stem, the upper disk controlling the quantity of gas admitted to the cylinder, and the lower disk regulating the flow of air. In this manner the inlet valve performs also the function of the carbureter used for gasoline motors with this difference, that no mixture is admitted to the valve passages, but the gas and air are mixed just before entering the cylinder. Both the inlet and exhaust valve are operated by tappet arms from a single cam attached to the **lay shaft** which runs parallel to the cylinder bores and is driven by spiral gears from the crank shaft at half speed.

The speed regulating mechanism for this engine consists of a centrifugal type of governor which controls the amount of lift of the inlet valve by means of a roller sliding over the top of the inlet valve tappet arm. (See Fig. 56.) In case the speed rises above normal, the governor moves this roller closer to the valve stem, decreasing its lift, and thus cutting down the supply of gas and air to the cylin-

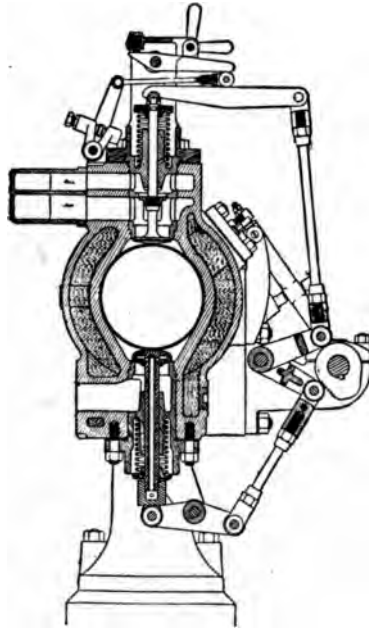


Fig. 56
Cross Section of Horizontal
Tandem Engine built by the
Elyria Gas Power Co.

ders. When the speed falls below normal, the roller is moved farther away from the valve stem and the supply of explosive mixture is increased sufficiently to bring the speed of the engine to the proper value.

SAINT MARY'S TANDEM ENGINES.

A type of stationary gas motor used for developing mechanical power on a fairly large scale (from 75 up to 500 HP.) is illustrated in Figs. 57 and 58, which are two views of the heavy duty horizontal tandem engine built by the St. Mary's Machine Company.

Fig. 57 is a longitudinal section taken through the center line of the cylinder bores, showing the tandem arrangement of the two cylinders and the location of the valves, which is similar to the arrangement in the Elyria engine.

Fig. 58 is a cross-section made through the middle of one of the cylinders and the valves, showing the method of operating them by means of an eccentric keyed to the lay shaft, the eccentric transmitting its motion to the valves by means of rolling levers and tappet arms.

The inlet valve has a double disk arrangement for controlling the **quantities** of gas and air admitted to the cylinder through two separate ports. The proper **quality** of the explosive mixture, or the relative volumes of gas and air may be adjusted for any condition of operation by means of separate gas and air throttle valves located in their respective ports. (See Fig. 58.) The speed in this engine is regulated by a centrifugal type of governor which controls the amount of lift of the inlet valve by means of a sliding roller in the same manner as in the Elyria engine. The cooling system in the larger

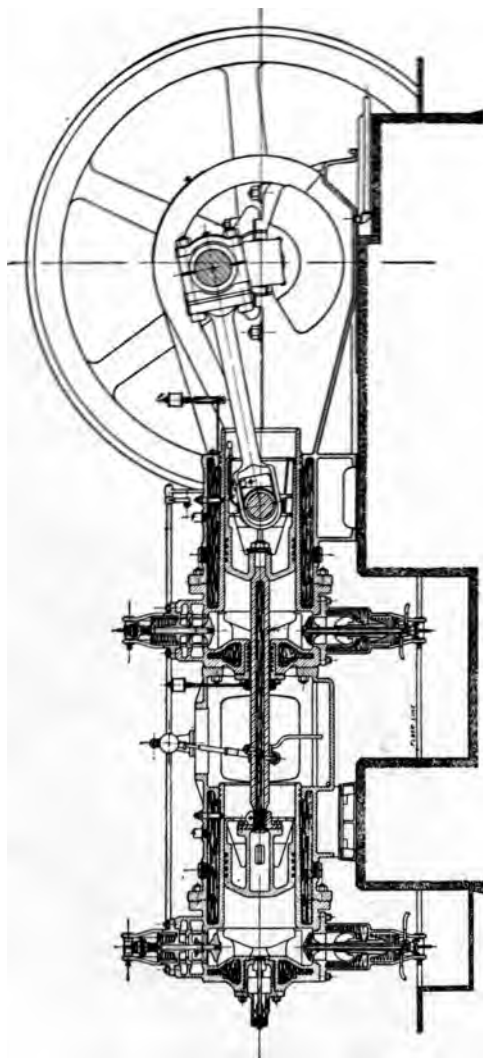


*Fig. 57.
Longitudinal Section of Tandem Engine
built by St. Mary's Machine Co.*

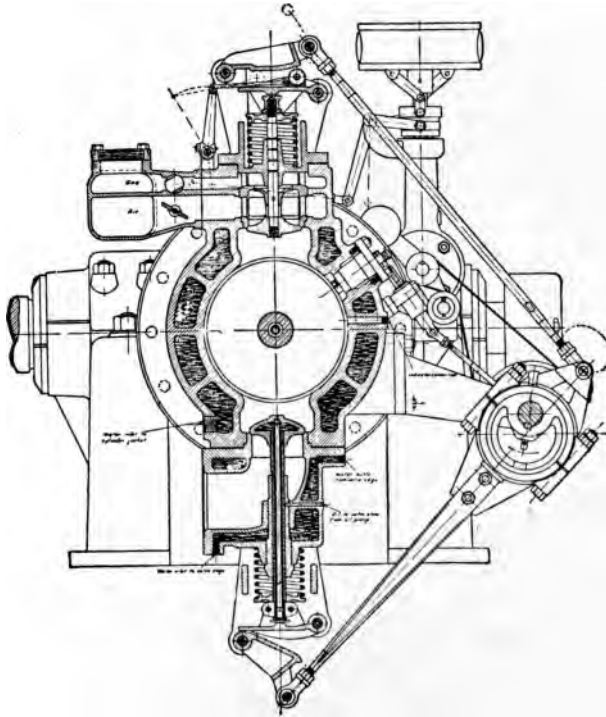


Fig-58.
Cross-Section of
St. Mary's Tandem Engine

sizes of St. Mary's engine is very elaborate, as shown in Fig. 58, which clearly indicates the numerous water jackets placed all around the cylinders, also around the exhaust piping, and even inside of the

exhaust valve, which is built hollow to provide for proper circulation of cooling water in the valve stem and head. This is made necessary on account of the large volumes of fuel burned in these heavy duty gas motors, and the high compressions and temperatures employed with this method of valve control.

DUPLEX GAS ENGINES.

Another method of arranging the cylinders of the smaller sizes of stationary motors is shown in Fig. 59, which is a longitudinal section of St. Mary's duplex engine, taken through the center line of the valve chamber.

The two cylinders are placed alongside of one another, near one end of the crank shaft, with the lay shaft located between them, and both the inlet and exhaust valves are located in a separate valve chest placed at the other end of the crank shaft.

The engine is provided with a flyball type of governor and a heavy flywheel in order to insure a practically constant speed, which makes this type of engine particularly well adapted for driving electric generators.

FUEL INJECTION IN THE DIESEL MOTOR.

In the ordinary types of stationary gas motor described above the thermal efficiency of the engine is limited by the amount of compression which can be safely carried in the cylinder without causing pre-

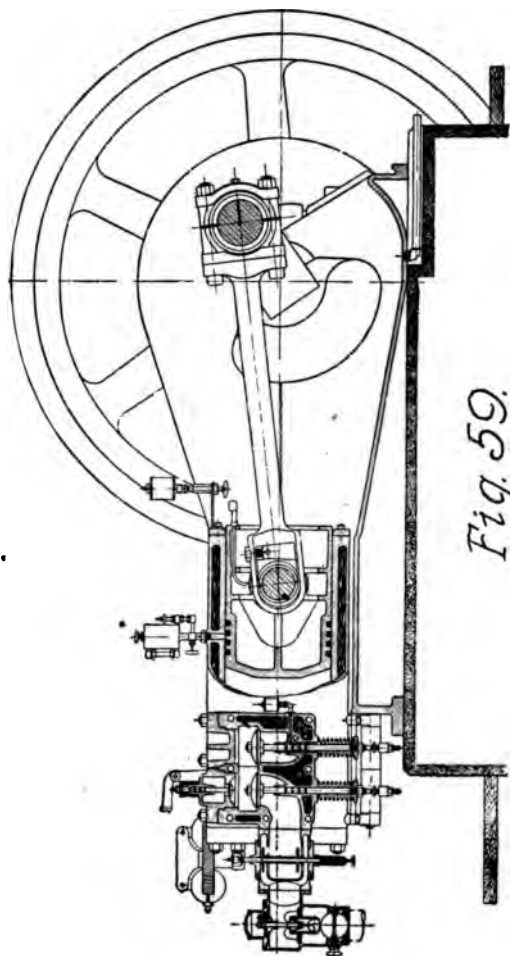


Fig. 59.

*Longitudinal Section of Horizontal
Duplex Engine built by St. Mary's Engine Co.*

ignition and back firing, due to the fuel reaching the ignition temperature before the end of the compression stroke. This limitation is partly overcome in the **Diesel** gas motor, by the method of keeping the fuel out of the cylinder until the end of compression, the piston compressing pure air up to about 500 lbs. per square inch; and by admitting the fuel into this compressed air just at the end of the compression stroke. This fuel, in the form of crude oil, is injected into the cylinder under pressure (about 700 lbs. per sq. inch) high enough to force it against the compressed air in the combustion chamber, and the heat developed by compressing the air is sufficient to ignite the mixture.

The operation of the Diesel gas motor is based on the following conditions in the combustion chamber:

(1) The **maximum compression** of the mixture is obtained by compressing pure air and injecting liquid fuel.

(2) **Ignition** is provided by compression.

(3) Highest **pressure** and combustion **temperature** are attained before combustion actually takes place, by the action of the piston.

(4) The **air** is compressed without heat losses, directly to the maximum pressure of the explosion.

(5) **Fuel** is introduced gradually, without sudden rise in temperature during combustion.

(6) A surplus of air is provided, insuring **complete combustion**.

A detailed description of one of the largest Diesel

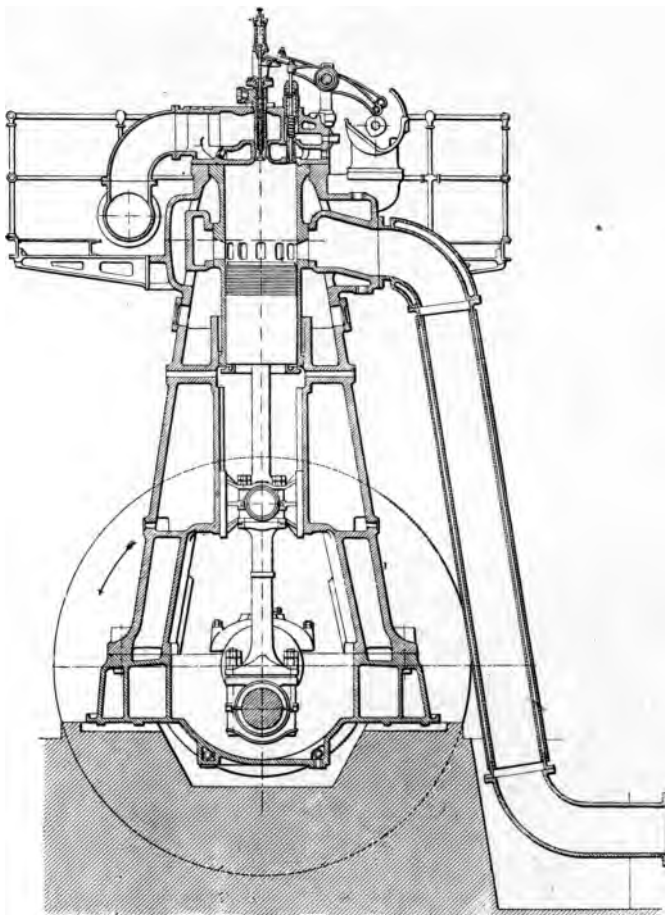


*Fig. 60.
Cross-Section of four-cylinder
Vertical 1000 H.P. Diesel Motor.*

motors built recently to supply power for a pumping station at Gladstone Dock, Liverpool, was given in the magazine "Engineering," September 12, 1913, from which we have obtained the following data:

The pumping station contains five units, each composed of a 54-inch Worthington centrifugal pump, direct-connected to a 1000 brake-horse-power Carels-Diesel engine.

The engines are of the vertical, two-cycle, four-cylinder Diesel type supplied by the Consolidated Diesel Engine Manufacturers, Limited, running normally at 180 revolutions per minute. Each of the cylinders has a diameter of 510 millimeters, the piston stroke being 660 millimeters, and the mean effective pressure is 6.75 atmospheres, or about 99.2 lbs. per square inch.

Two fuel pumps are employed in each engine, each pump having two plungers, one for each cylinder. The burned gases are driven out of the cylinder by two scavenge pumps delivering fresh air at about 5 lbs. per sq. inch to the scavenge valves, four of which are located in each cylinder cover.

Fig. 60 is a cross-section of one of the Diesel units, and Fig. 61 is a partial longitudinal section, showing the arrangement of cylinders and main piping connections.

Each unit is equipped with a high-pressure air

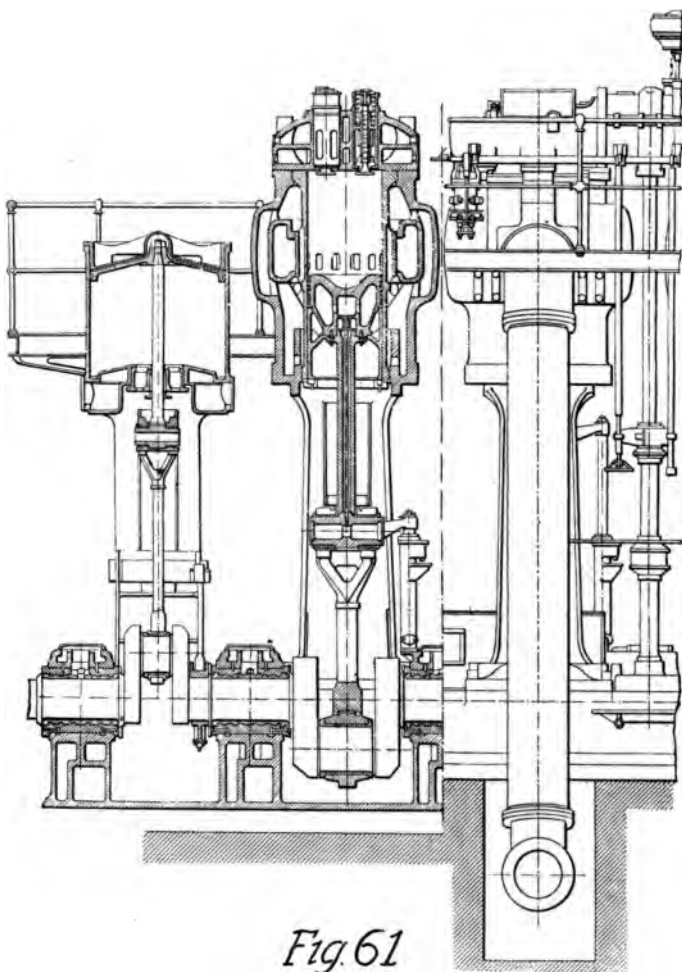


Fig. 61
Longitudinal Section of the 1000 H.P.
Diesel Motor.

pump of the quadruplex water-cooled type, delivering air for fuel injection and starting purposes.

Another modern application of the Diesel motor, for propelling large airships, may be illustrated by the following quotation from the "Chicago Tribune" of October 23, 1917:

"CAPTURED 'ZEP' HAS FIVE MOTORS."

"Bourbonne Les Bains, France, Oct. 22.—The L. 49, the only Zeppelin to fall into the hands of the allies intact, struck its colors to the shotgun of a local workman named Boiteux. Lieut. Lafargue of the 'Crocodile' escadrille winged the Zeppelin, forcing it to land.

"Gen. de Castelnau and M. Dumesnil, undersecretary for aviation, who visited the Zeppelin Sunday morning, congratulated Boiteux on his presence of mind and enterprising courage which preserved the airship, which will be a fruitful source of study for French aeronautical experts. He will be given suitable recognition by the government.

"The L. 49 has five motors of 250 horse power each, and four cars, the middle ones of which contain two of the engines and all the levers and instruments. The small balloon had a total capacity of 5,000 cubic meters. The airship was able to make fifty or fifty-five miles an hour. The L-49 was a naval airship of the most recent type, was fitted with all latest improvements, and was almost brand new." The motors referred to in the above quotation were of the latest Diesel type.

The recent improvements in the construction of high-powered air compressors adapted for supplying air to internal combustion engines has made it practicable to use the stationary type of gas motor for propelling submarines.

The actual details for propelling submarines by means of gas power were first worked out by Mr. A. R. Neff, a marine engineer. His method consists mainly of providing a pair of powerful air compressors direct connected to the main shaft of the gas engine, consuming about 150 HP. for their operation on a boat of about 1000 tons. The air is compressed to 3000 lbs. per sq. inch and stored in steel flasks, the total air equipment weighing about 160,000 lbs. and occupying a space of about 1600 cubic ft. The exhaust from the gas motor is forced out of the submarine against the water pressure by means of the energy stored up in the compressed air, which drives a double acting force pump used as a "mechanical exhaustor."

The compressed air from the storage flasks is led to a special pressure-reducing valve, which decreases its pressure to 150 lbs. per sq. inch, then the air is reheated to about 400 degrees F. before being admitted to the cylinders of the motor.

The advantage of this method of submarine propulsion consists mainly in the entire freedom from fumes from the storage batteries which is inherent with the electric drive, and the abundance of fresh

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The advantage of this method of submarine propulsion consists mainly in the entire freedom from fumes from the storage batteries which is inherent with the electric drive, and the abundance of fresh

air at all times, whether the boat is afloat or submerged.

The application of this system to United States submarines would have probably prevented the loss of the United States boat, F-4, which was caused by the battery fumes; and the explosion on the United States boat, E-2, which was started by the ignition of accumulated hydrogen gas.

CARE OF STATIONARY GAS MOTORS.

In operating stationary gas engines of any considerable size, great care must be taken to have the proper adjustments for the maximum economy possible with each type of motor, as the question of efficiency is the determining factor in their operation.

The parts of the motor liable to be ruined by insufficient oiling or cooling must be frequently inspected, since in the large sized engines the parts are very expensive and hard to replace. In engines used for driving electric generators the governor must be carefully regulated to insure practically constant speed, since any variations from the normal value produce fluctuations in the generator current.

In order to avoid most of the cylinder troubles in the stationary gas engine, all the parts must be kept clean from dirt, rust and moisture. This applies particularly to the electrical equipment, since a failure of the spark may cause misfiring in one of the

cylinders. Such a sudden failure in power delivery to the shaft is very injurious on large units having few cylinders and driving heavy flywheels, since the shock may strain the working parts of the engine sufficiently to break them or to throw them out of alignment.

The valve mechanism should be frequently adjusted, and all loose connecting pins fastened tight, as any appreciable play in the valve operating levers, rods, or tappet arms affects the amount of valve lift and, consequently, it allows a variation in both the quantity and quality of mixture from the values best suited for that particular type of motor.

QUESTIONS ON CHAPTER VIII.

1. Name the principal parts of a gas producer plant, and their functions in generating fuel for gas engines.
2. Compute the approximate quantity of coal used per hour in generating uncarbureted water gas which is supplied to a 100 HP. engine, operating with a thermal efficiency of 25%.
3. What are the conditions affecting the amount of mechanical power developed in a stationary gas motor?
4. A double-acting, four-cycle, two-cylinder horizontal oil engine has a cylinder bore of 24 inches, a piston stroke of 30 inches, and a normal speed of 125 revolutions per minute. What is its rated Horse Power at the brake?

5. Assuming a thermal efficiency of 18% for the engine specified in question 4, what is its oil consumption in gallons per hour, the density of the oil being 6.5 lbs. per gallon, and its heating value about 19,000 B.T.U. per lb.?

6. What is the advantage of the tandem arrangement of cylinders?

7. Compare the relative merits of the "hit-or-miss" and the "throttling" methods of speed governing.

8. What is the advantage gained by scavenging the gas engine?

9. How is back-firing prevented in modern large stationary gas engines?

10. What are the principles of operation of the Diesel gas motor?

11. What conditions must be fulfilled before the gas motor can be used for propelling submarines?

12. What are the advantages to be gained by using gas power for submarines instead of storage batteries?

ANSWERS TO QUESTIONS ON CHAPTER VII.

1. The rate of heat radiation depends upon the following conditions: The size of radiating surface; the thickness of the communicating walls; the difference in temperature between the two substances; the specific heat of the cooling medium; the rate of circulation.

2. The cooling of cylinder walls lowers the thermal efficiency of the motor, by decreasing the difference in temperature between the combustion chamber and the exhaust pipe.

3. The temperature of the cylinder walls is limited by the physical qualities of the metal, by greater piston and valve troubles at high temperatures, and by the difficulty of properly lubricating the cylinder at temperatures higher than 450° F.

4. The air-cooling system of a two-cylinder motorcycle engine consists merely of ribs or projections cast solid with the cylinder walls, to provide a large radiating surface.

5. The water-cooling system of a 50 HP. six cylinder motor is made up of water jackets with proper piping; a radiator; a cooling fan, and a water circulating pump.

6. The plunger type of circulating pump is very efficient and simple in operation, but it is not very powerful and it requires a great deal of attention.

7. The centrifugal type of circulating pump operates on the principle of centrifugal force imparted to the particles of water due to their rotary motion, which throws them towards the outward edges of the casing and into the discharge pipe, thus creating a suction in the inlet pipe.

8. A 40 HP. gas engine using the thermo-siphon cooling system requires a radiating surface equal to:

$$5 \times 40 = 200 \text{ square feet.}$$

9. The use of a 50% solution of calcium chloride lowers the freezing point of the cooling mixture to about 15° F, which prevents bursting of the water jackets and piping during ordinary freezing weathers.

10. The addition of slaked lime to the non-freezing salt solution neutralizes its acidity and prevents the corrosion of metal in the cooling system.

11. Failure in any part of the cooling system causes overheating of the cylinder and bearings, preventing proper lubrication; also causing preignition, back-firing and carbon deposits in the cylinder and valve passages.

12. The deposit of scale can be removed from the water circulating system by filling the water spaces with a 5% solution of hydrochloric acid for 10 or 12 hours, then draining it off and thoroughly flushing the system with pure water to remove all traces of the acid.

CHAPTER IX.

AUTOMOBILE MOTOR TRANSMISSION.

The mechanical power developed in the gas motor used for driving automobiles cannot be applied directly to the driving wheels located at the rear of the car, since, in the first place, the normal speed of the engine is in most cases too great for the requirements of the load, road conditions and practical rates of travel. Secondly, a direct drive from the engine would involve the necessity of stopping the engine every time a short stop is made, which would be very annoying and would cause a considerable loss of time, making it almost impossible to drive the car through the crowded business district of a large city. Another objection to applying the engine power directly to the wheels is the difficulty of rounding corners, in which case the outside rear wheel has to travel faster than the inside rear wheel, causing slipping of the slower wheel, which is both dangerous and wasteful of material. Proper means must also be provided for making the connection between the engine and the driving wheel flexible, to allow for the free movements of the driving mechanism to conform with the jarring and jolting of the car on rough roads. Finally, the system of power transmission from engine to wheels must also include

some braking device for absorbing the power of the engine as soon as the power is shut off, so as to bring the car to a quick stop.

Due to the above requirements, the power transmission system of a modern automobile driven by a gas motor includes the following equipment:

1. A speed-changing device by means of either friction disks, pulleys or gears, popularly known as the **transmission**.

2. A means for disconnecting the engine from the driving mechanism, in the form of a **clutch**, which is usually applied to the flywheel of the engine.

3. A **flexible joint** in the driving shaft connecting the engine to the differential transmission mechanism, to allow the various parts of the shaft to operate out of line without undue strain.

4. A mechanical device for driving the two **rear** wheels independent of one another from the **same** shaft, to equalize their difference in speed when rounding curves or on uneven roads. This is known as the **differential** transmission.

5. One or more **brakes** applied either at the driving shaft or at the wheels in order to bring the car to a quick stop.

The general arrangement of the power transmission system on a modern gas-driven car is shown in Fig. 62, where the engine is located in front of the car at (E) with the flywheel (F) and clutch (C) in the rear of the engine. The speed-changing transmission is placed at (T), the flexible coupling at (J),

and the differential gearing at (D). The foot-brake (B) is attached to the transmission gearing. The machinery of the car is supported to the steel frame, which is provided with proper cross-bracing to give rigidity to the whole structure.

The most positive method of transmitting the power from the engine to the wheels is by means of toothed wheels, or **gears** which engage or **mesh** with one another so as to change either the speed, or both the speed and direction of rotation of the shafts to which these gears are fastened. In order to better understand the transmission system of the modern gas-driven automobile we must first consider the general action of various types and systems of gearing.

MECHANISM OF GEARING.

Whenever two gear wheels of different sizes are securely fastened to the same shaft, the angular velocities are necessarily equal, which means that they both revolve at the same rate of speed; but the **linear velocities** of their teeth are different, *i. e.*, each tooth on the larger sized wheel travels in space faster than the tooth on the smaller wheel in the direct ratios of their respective number of teeth. The size of any gear wheel is usually measured by its **pitch diameter**, which is the distance across the center between two opposite points at which the teeth mesh with the other gear. This is somewhat smaller than the **outside diameter** between the ex-

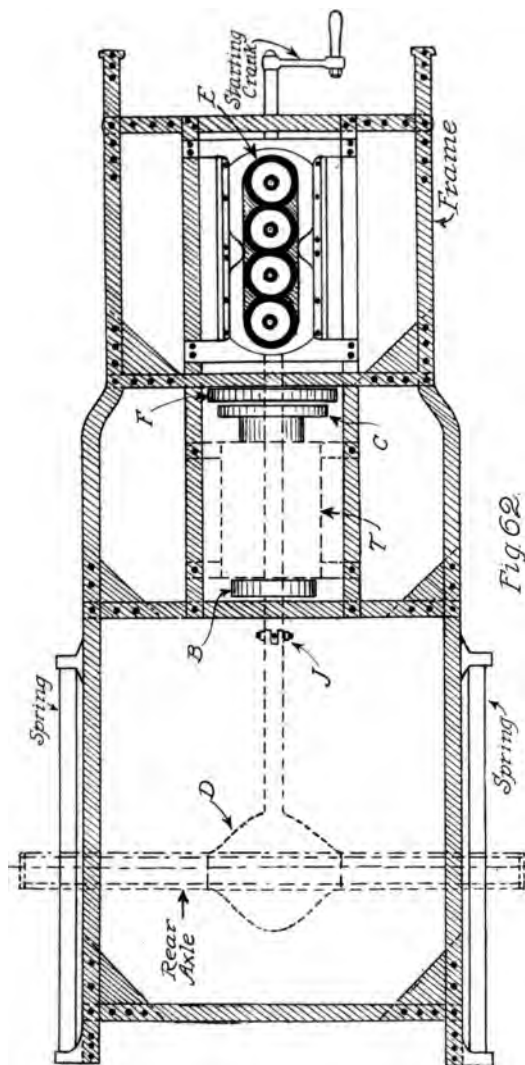


Fig 62.
Automobile Power Transmission System

treme points of the teeth. The distance between the middle points of any two consecutive gear teeth is known as the **circular pitch**.

In Fig. 63, which represents a spur gear wheel, the outside diameter is marked **O. D.**, the pitch

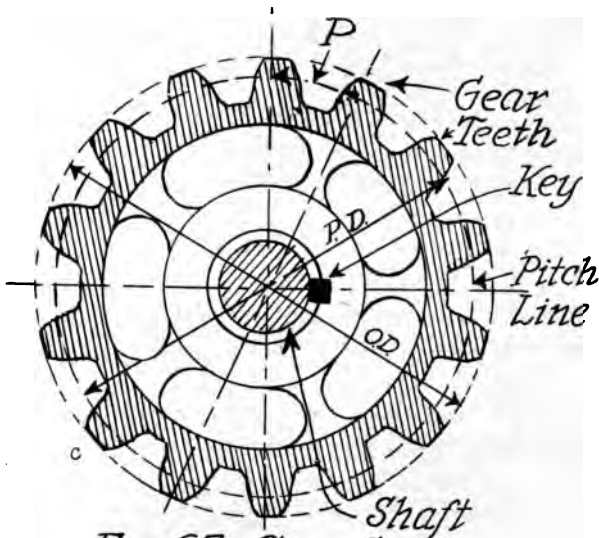


Fig. 63~Spur Gear

diameter is **P. D.**, and the circular pitch is noted as **(P)**.

The circular pitch of any gear wheel can be computed by knowing its pitch diameter and the number of teeth, by the following rule:

$P = (D \times 3.1416) \div N$ (1)
 where **P** is the circular pitch in inches, **D** is the pitch diameter in inches, and **N** is the number of teeth.

The linear velocity of the teeth is equal to the product of the pitch diameter times the number of revolutions per minute multiplied by 3.1416. This tooth velocity can be computed in ft. per minute by the following formula:

$V = D \times R \times 0.2618$ (2)
 where **V** is the linear velocity of the teeth in ft. per minute, **D** is the pitch diameter in inches and **R** is the number of revolutions per minute.

To illustrate this, let us assume a shaft running at 100 revolutions per minute having two gears keyed to it, one having a pitch diameter of 10 inches, and the second one having a pitch diameter of 6 inches. The tooth velocity in the first wheel is equal to:

$10 \times 100 \times 0.2618 = 261.8$ ft. per minute; in the smaller wheel the linear velocity of the teeth equals to:

$6 \times 100 \times 0.2618 = 157.08$ ft. per minute.

The maximum velocity allowed for ordinary steel gear teeth is about 2400 ft. per minute.

The load carried by gear teeth can easily be computed, by dividing the total ft.-lbs. transmitted by the gear, into the tooth velocity, this relation being as follows:

$F = (HP. \times 33,000) \div (D \times R \times 0.2618)$.. (3)
 Where **F** is the pressure on the teeth in pounds, **HP.**

is the horse-power transmitted, **V** is the tooth velocity in feet per minute, **D** is the pitch diameter in inches, and **R** is the number of revolutions per minute. For steel gears having a tooth velocity of 1000 ft. per minute, the allowable tooth pressure is about 15,000 lbs. per sq. inch of metal.

When two gears are fastened to two separate shafts and meshed so that one shaft transmits the power to the second one, their angular velocities are in the inverse ratio of their respective number of gear teeth, *i. e.*, the shaft having the larger gear wheel will revolve slower than the shaft with the small gear, according to the relative number of their teeth. This rule can be expressed as follows:

$$R \div r = n \div N \dots\dots\dots (4)$$

Where **R** is the number of revolutions per minute of the shaft having the large gear, and **r** is the number of r.p.m. of the shaft having the small gear, or **pinion**, **n** = is the number of teeth on the pinion, and **N** is the number of teeth on the large gear wheel. Thus a drive of 60 teeth to 6 teeth increases the speed ten times, assuming no friction losses.

The tooth velocities of any two gears in mesh are always equal.

SPUR AND BEVEL GEARS.

For changing the relative speeds of two parallel shafts without changing the angle of drive, a system of spur-gears is used, the gears being of the shape shown in Fig. 63. In some cases one of the

spur gears has the shape of a straight rod or beam to which the gear teeth are attached. This is called a **rack**, and it is used to change the reciprocating motion of the rack to the rotary motion of the gear, or vice versa.

In order to change the angle of drive of two

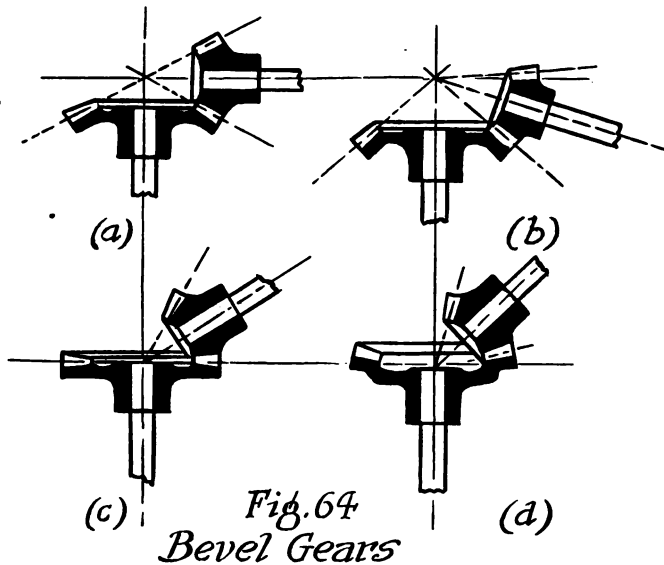


Fig. 64
Bevel Gears

shafts, the system of **bevel gearing** is used as indicated in Fig. 64, where (a) is an ordinary type of bevel gear drive with shaft at right angles, (b) shows bevel gears for shafts running at angle less than 90 degrees, (c) is an illustration of the so-called

crown bevel gears, and (d) shows **internal** bevel gears. Formula (4) applies to bevel gears as well as to spur gears, providing the two gears mesh with one another.

WORM GEARS.

In order to obtain a relatively great reduction in speed without using many gears, the system of worm gearing is often used, as shown in Fig. 65. In this case the large gear wheel (G) having a pitch of (p) inches, meshes with the screw-thread cut on the second shaft or **worm** (w) in such a manner that at every revolution of the worm the gear wheel advances only one tooth, so that the total reduction in speed depends on the number of teeth on the gear. Thus, in a worm-gear system using a gear having 60 teeth on its rim, one complete revolution of the worm will move the gear only 1/60 of a revolution, or one revolution of the gear wheel will revolve the worm shaft 60 times.

The worm gear system is often used for the purpose of obtaining a large force with a relatively small effort, at the sacrifice of loss in speed.

Since the total amount of mechanical work transmitted in any device is equal to the product of the force times the distance through which this force travels, the forces at the two ends of the transmission system shown in Fig. 65 is as follows:

$$(W \times R) \div N = F \times A \dots\dots\dots (5)$$

Where **W** is the tooth pressure in pounds, **R** is the

pitch radius of the gear wheel in inches, N is the number of teeth on the wheel, F is the force in lbs. applied at the handle, having an active radius equal to A inches.

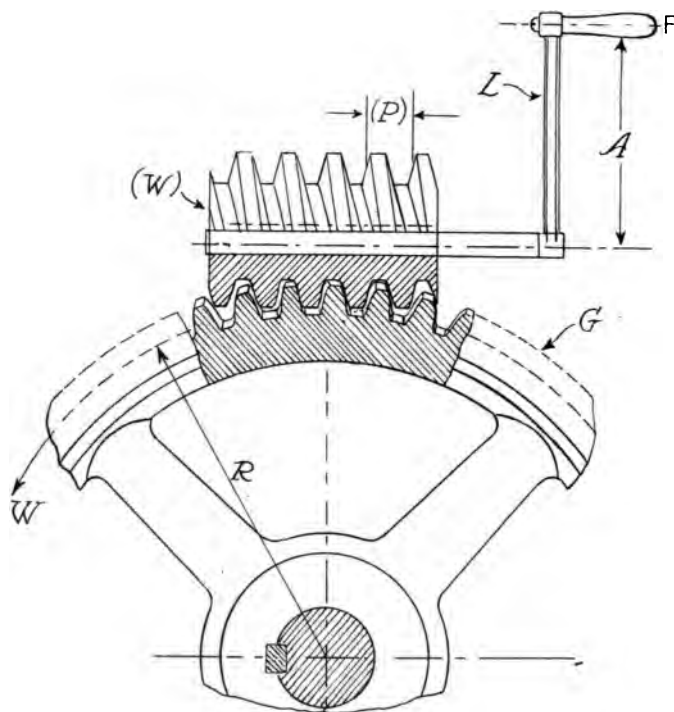


Fig. 65~Worm Gear

PLANETARY GEARS.

A mechanical transmission system may be made up of any combination of spur gears, bevel gears, worm gearing, or other similar devices according to the requirements of speed or power reduction. A very common arrangement of spur gears used for speed reduction on light automobiles, known as the **planetary** system of gearing is illustrated in Fig. 66.

It consists mainly of two drums (A) and (B), which are free to move on the engine shaft (E), and are free relative to one another. Gear 1 (see Fig. 66) is keyed to the engine shaft, so that it always revolves with it. Gear 2 is firmly attached to a sleeve which is fastened to the center opening in drum A so that it can turn with drum A loosely on the engine shaft. Gears 3, 4, 5, 6, 7 and 8 are equally spaced on studs fastened to drum B, so that each of these gears can turn loosely on its stud, and all the studs are revolved with drum B. Gears 4 and 5 are omitted in the figure for the sake of simplicity. These small gears are arranged in such a manner that gear 4 meshes with gear 3, 6 meshes with 5, and 8 with 7; also all the three gears, 4, 6 and 8, mesh with gear 1, which is keyed to shaft E, and the three gears, 3, 5 and 7, mesh with gear 2, which is fastened to drum A.

Drum B is usually closed by cover plate (C), which is fastened to it by a number of screws. This cover contains a large internal gear 9 rigidly connected to sprocket (S), which transmits its motion

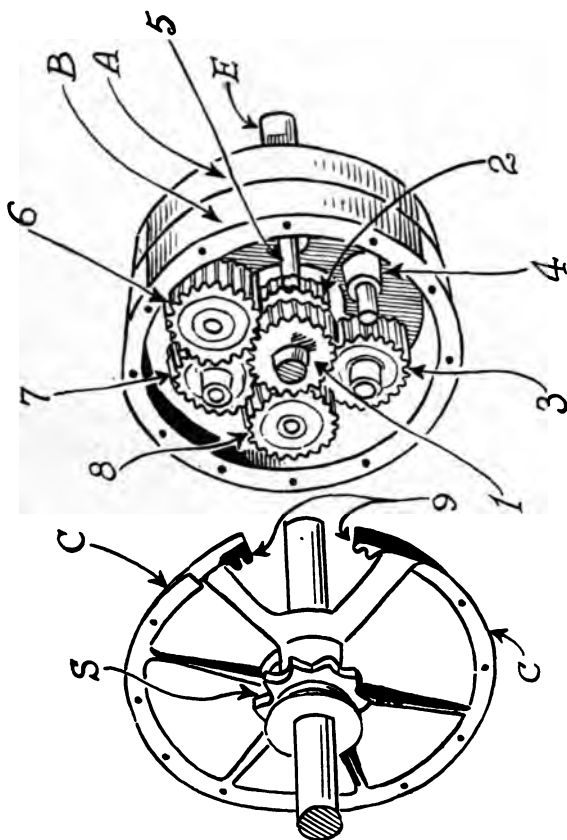


Fig. 66
Planetary Gears

to the driving shaft. The internal gear 9 meshes with the three small loose gears, 4, 6 and 8, located in drum B.

This transmission system is also equipped with a **friction disc** which can be pressed against the face of drum A, and with two separate **brake bands** fitting around drums A and B, so that either drum can be held stationary, while the other is revolving.

The operation of the planetary system is as follows:

(1) **Direct drive** from engine is obtained by forcing the friction disc against drum A. This revolves drum A with the engine shaft, and the whole system acts as a shaft coupling, transmitting the engine speed directly to the driving sprocket S, the gears 3, 4, 5, 6, 7 and 8 being in this case stationary and acting as links between the two drums and the driving gear 9.

(2) **Slow speed** is obtained by relieving the pressure of the friction disc, and tightening the brake band around drum A. This holds drum A and gear 2 stationary, while gear 1 revolves with engine shaft E. This motion is transmitted to gears 4, 6 and 8, and these drive gears 3, 5 and 7, and also drum B around stationary gear 2, in the same direction as the engine shaft but at a lower speed. Since gears 4, 6 and 8 revolve with drum B, and also mesh with internal gear 9, they drive the sprocket S at a slow forward speed.

(3) **Reverse drive** is accomplished by releasing

brake band around drum A and tightening brake on drum B. This keeps gear studs 4, 6 and 8 stationary with drum B, but revolves these gears on their studs. This drives the internal gear 9 in a direction opposite from the engine shaft, giving a backward motion to the driving shaft and to the wheels of the car.

(4) The engine may be entirely disconnected **running idle** without driving the car, by releasing both brakes and the friction disc, in which case the gears do not transmit any power to the driving sprocket.

The advantage of the planetary type of gearing is the low cost of this type of transmission system and the simplicity of its operation. It is, however, limited in its power capacity and its available range of speed, so that it is best suited for the lighter cars running at moderate speeds, where a more expensive transmission system would not be justified.

DIFFERENTIAL GEARS.

Any transmission system, by means of which two shafts running in one continuous line may be revolved independently at different speeds from the same driving shaft, is known as a **differential** system of gearing. This may be obtained by using a combination of planetary gears, spur gears or bevel gears, or in some systems by means of a special mechanism having no gears, known as the **Russel's Gearless Differential**. In most of these differential

systems, the driving shaft transmits its motion to the differential gear case by means of either a chain and sprocket or a bevel gear, the sprocket wheel or bevel gear being rigidly connected to the case. This revolves the case at right angles to the main driving shaft. The two parts of the shaft which transmits its motion to the rear wheels of the car usually terminate in either spur or bevel gears, as the case may be, inserted in proper openings of the differential gear case and driven so that each part of the shaft can revolve independent of the other at a speed required by its corresponding wheel. This permits the car to turn a corner without any of the rear wheels slipping, by allowing the inside wheel to revolve slower than the outside wheel, although they are both driven from the same main shaft.

SLIDE GEAR TRANSMISSION.

Fig. 67 is a simplified diagram of a modern slide gear transmission system used for obtaining three forward speeds and one reverse speed, by shifting two gears on the **main driving shaft**, relative to a number of fixed gears keyed to a **secondary**, or countershaft, with which the slide gears are engaged by means of a shifting lever.

Referring to Fig. 67, M is the main shaft connected to the engine shaft by means of a clutch and the flexible coupling J. This part of the main shaft is made hollow, like a sleeve, in which the driving shaft N is free to revolve unless it is locked to it by

shifting the slide gears to the extreme right position. In that case, the slide gears 7 and 8 are not in a mesh with any of the gears on the countershaft, and the driving shaft (N) runs then at its highest speed, equal to the speed of the engine shaft (M).

The rotary motion from engine shaft M is transmitted to the secondary shaft S by means of gear 1,

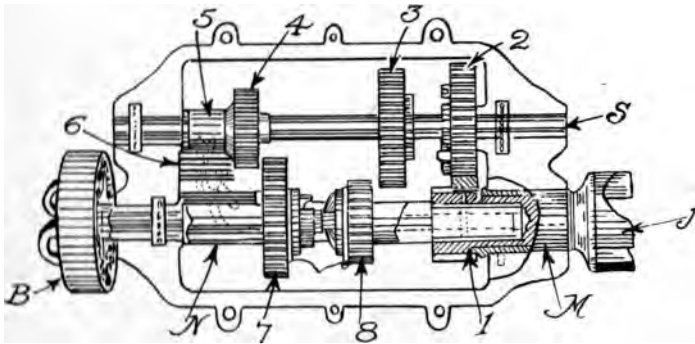


Fig. 67~ Three-Speed Slide Gears

keyed to the hollow part of shaft M, this gear being always in mesh with gear 2, which is keyed to the countershaft. With the **direct drive**, the countershaft runs idle, since none of its gears are in mesh with the slide gears on shaft N.

For **second speed**, the slide gears are shifted so that gear 8 meshes with gear 3. The order of driving is then as follows: Shaft M rotates with engine. Gear 1 drives gear 2 in direction opposite to shaft M. Gear 3 drives gear 8, which transmits its rotation to driving shaft N, in same direction as shaft M,

but at lower speed, on account of the relative size of gears 1 and 2.

The third or **lowest speed** is obtained by shifting the slide gears farther to the left until gear 4 meshes with gear 7. Since the tooth ratio between 7 and 4 is greater than tooth ratio between 8 and 3, we obtain a correspondingly lower speed with this position of the gears.

In order to **reverse** the motion of the driving shaft, the slide gears are shifted to their extreme left position, engaging gear 7 with the small idle pinion 6, which is free to turn on its stud attached to the transmission case, and which is always driven by pinion 5 keyed to the countershaft. This drives shaft N in an opposite direction from shaft M and thus provides means for giving the car a backward motion.

For quickly absorbing the power after the engine is shut off, the foot-brake B is attached to the driving shaft N near the transmission case.

Fig. 68 shows a slide gear transmission system which provides for four different forward speeds and one reverse, by having three slide gears with a corresponding number of fixed gears on the countershafts. In all other respects the operation is the same as on the three-speed system shown in Fig. 67.

DIFFERENTIAL GEAR TRANSMISSION.

A very common system of differential gearing used with a **double-chain drive**, and usually attached to the slide gear transmission case, is shown in Fig.

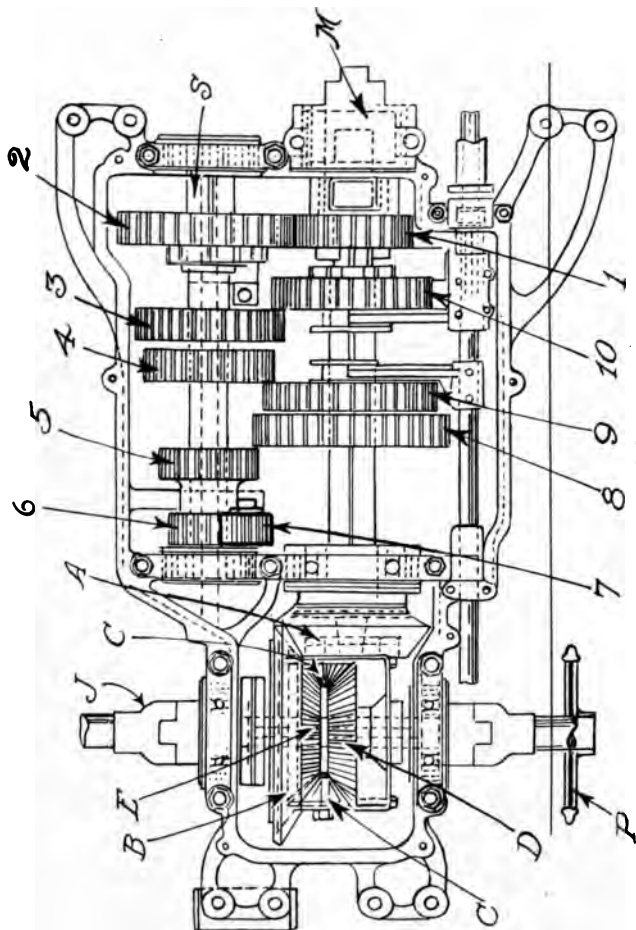


Fig 68.
Four-Speed Slide Gears and Differential Bevel Gears

68. The two halves of the cross-shaft or **jack-shaft** (J) transmit their motion to the rear wheels by means of sprockets (P) keyed to them, and terminate in two large bevel gears, D and E, located in the differential gear case. This case is driven from the main driving shaft by bevel gears A and B, gear A being keyed to the driving shaft and gear B firmly attached to gear case. Several small bevel gears (C) are equally spaced inside the gear case, arranged so as to turn freely on their studs which are rigidly connected to the case. These gears are always in mesh with the bevel gears D and E keyed to the two halves of the jack-shaft. By means of this arrangement the two bevel gears D and E can rotate at different speeds, the difference between their relative motion being compensated by the rotation of the small bevel gears C on their respective pins. In case both rear wheels of the car rotate at the same speed, then the small bevel gears C are stationary on their pins, and they act then merely as driving links between the case and the jack-shaft, the whole differential gear system operating as a solid unit.

RANGE OF SPEEDS.

The actual speed of the car depends not only upon the arrangement of its transmission gears, but also upon the speed regulation of the engine proper, and upon the amount and character of the load. The speed of the engine is controlled either by varying the quantity or quality of the fuel; by regulating the time of ignition; or, in some cases, by omit-

ting a number of explosions. The load at the wheel depends upon the condition of the road, the number and size of grades, and the total weight carried. As a result of all these conditions affecting the velocity of the car, we can obtain a wide range of speeds, the maximum speed being with the engine running at its highest power capacity, the gears being engaged for direct drive, and the road being fairly smooth and level. Some operators make frequent use of the partial slipping of the clutch or brakes to regulate the speed in this manner. This practice is wasteful of material and such a method of speed regulation is neither positive nor efficient. The regulation of speed by varying the fuel supply, or retarding the spark usually results in a waste of fuel, since the engine does not operate at its best economy under such conditions. The ideal method of speed regulation of an automobile is to operate the motor at its maximum efficiency and make all the changes in speed by means of the transmission system. In that case the range of speeds depends upon the number and arrangement of gears in the system, or, in case of a friction drive, it depends upon the size and relative position of the transmission discs.

The choice must be, therefore, made between the expense of first installation of a transmission system having a wide range of speeds, and the loss in economy due to speed regulation by varying the operating conditions of the motor.

THE CLUTCH.

In order to provide a positive method for breaking the connection between the engine and the main driving shaft, some form of clutch is used, which normally make a more or less rigid connection between the two shafts, but which can be released by operating the proper lever provided for that purpose. According to their method of operation, all the clutches may be divided into the following classes:

(1) **Bevel or Cone** clutch, in which the connection is made by pressing the conical surface of the clutch against a similar recess in the flywheel (see Fig. 69).

(2) **Internal Expansion** clutch which grips the flywheel internally by means of a series of flat surfaces pressed inside the hollow rim of the wheel, by the action of a series of toggle joints (see Fig. 70).

(3) **External Expansion** clutch, acting in the same manner as the internal expansion type, only applying the pressure to the outside surface of the flywheel rim.

(4) Friction disc, or **Multiple disc** clutch, which connects the driving shaft to the flywheel by means of the pressure applied at the face of the wheel, and transmitted through a series of thin metallic discs (see Fig. 71).

(5) **Hydraulic clutch**, in which the resistance to compression by oil is utilized, by partially closing a series of valves leading to a chamber filled with oil,

and transmitting the motion of the engine shaft to the driving shaft through gears revolving in this oil chamber.

(6) **Magnetic clutch**, in which the two shafts are held together by magnetic attraction, maintained by

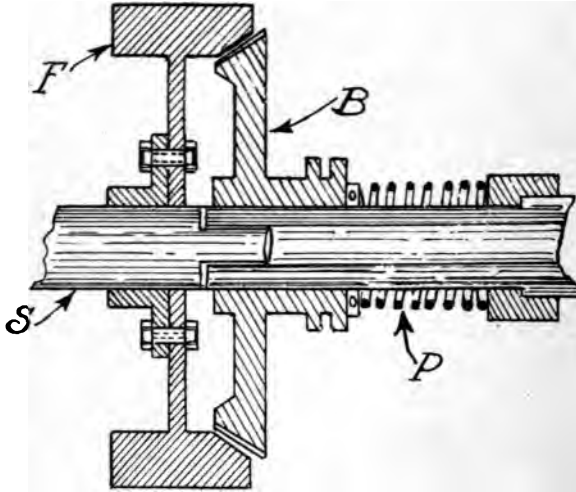


Fig. 69~Bevel Clutch.

a current flowing in the electro-magnetic coils of the clutch.

The bevel clutch is illustrated in Fig. 69, where F is the fly wheel, and B is the cone, usually provided with a leather facing or some special lining, to make the action of the clutch more gradual; P is the spring, pressing the bevel surface against the fly-

wheel, which is released by the operating lever, and S is the engine shaft.

In Fig. 70, which shows the internal expansion

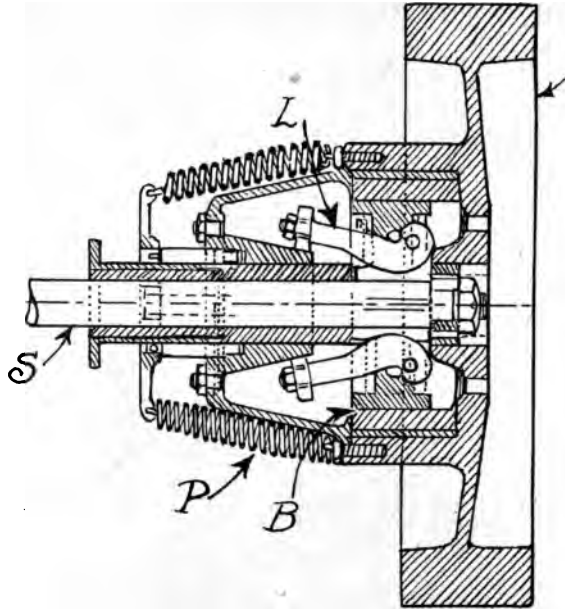


*Fig. 70~Internal
Expansion Clutch.*

type of clutch, S is the driving shaft, P indicates the operating springs, and B is the lined surface, normally held against the flywheel F by the toggle joints L.

The multiple-disc clutch shown in Fig. 71 operates by means of springs which press the discs D against the surface of flywheel. The break is made by

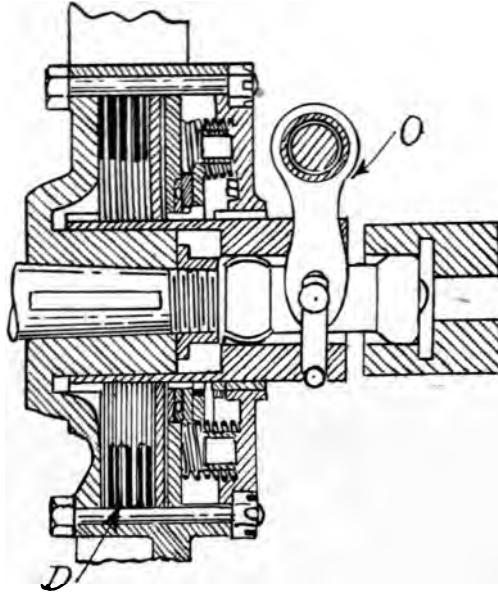


Fig. 71~Multiple Disc Clutch

operating lever O, which removes the pressure and disconnects the engine shaft from the transmission system.

CARE OF TRANSMISSION SYSTEM.

Most parts of the transmission system are more or less automatic in their operation, and they need

little attention under ordinary circumstance, except an occasional supply of proper amount of heavy oil or grease and ordinary care in their handling. The greatest source of trouble lies in the clutch, as upon its action depends the amount and character of power transmitted from the engine to the driving shaft.

A **slipping** clutch makes it impossible to obtain the proper speed with the gears arranged for any particular drive, and, in severe cases, it may stop the car altogether, on account of lack of friction between the bearing surfaces. On the other hand, a **fierce** clutch, or one possessing too great a holding force, may ruin the shafts and gears by the sudden grip of the transmission mechanism when the clutch pedal is released. These troubles should be quickly remedied by oiling the clutch lining; by cleaning the surface with gasoline; or by renewing the lining, in case it is badly worn.

Great care must be taken to disengage the clutch during the period of shifting from one speed to another, as failure to relieve the driving shaft during a change in speed may result in stripping of the gear teeth and other serious injuries to the transmission mechanism, on account of the sudden change in velocity imparted to the various parts of the system.

The loss in power due to frictional resistance in the transmission system is approximately as follows:

- (1) With a longitudinal shaft drive—30%-40%

(2) Right-angle drive by jack shaft and two chains—25%-30%.

(3) Double chain drive from motor to transmission and from transmission to rear axle—20%-25%.

(4) Single chain drive—12%-15%.

By a judicious use of oil, grease and proper care, these losses may be reduced to a minimum.

QUESTIONS ON CHAPTER IX.

1. Find the tooth velocity of a spur gear having a pitch diameter of 10 inches when it is driven at 1200 revolutions per minute.

2. What is the total pressure carried by the gear teeth of the wheel specified in question 1, when it transmits 20 HP. from the engine to the driving shaft?

3. Referring to Fig. 68, assume that the speed change gears have the following number of teeth:

Gear No. 1—20 teeth; No. 2—24 teeth; No. 3—18 teeth; No. 4—12 teeth; No. 5—9 teeth; No. 6—9 teeth; No. 7—12 teeth; No. 8—30 teeth; No. 9—24 teeth; No. 10—20 teeth. Give number of revolutions per minute of the driving shaft at various speed changes, when the engine runs at 1200 r.p.m.

4. What is the advantage in using a worm gear system for overcoming heavy resistances?

5. What are the relative merits of the **planetary** and the **slide gear** systems of speed changing?

6. Describe the function of the differential gearing.

7. What HP. is required at the wheels of a car weighing 2000 lbs. and running at 20 miles per hour, the road offering a resistance of 450 lbs. per ton?

8. Using a right angle longitudinal shaft driving system, what HP. is required at the clutch of the automobile specified in question 7?

9. With a mechanical efficiency of 85%, what is the power developed in the above motor?

10. Using a four-cylinder vertical engine, find the proper dimensions of the engine specified in questions 7 and 8.

11. Enumerate the various types of clutches used for automobile transmission systems.

12. What precautions must be taken before changing the speed of a car by shifting the gears?

ANSWERS TO QUESTIONS ON CHAPTER VIII.

1. A gas producer plant is made up of a **generator**, where the coal undergoes partial combustion; a **vaporizer**, which produces steam supplied to the generator; a **scrubber**, in which the gas is cooled and washed; and a saw-dust **dryer**, which removes the moisture and tar products of the coal.

2. To develop 100 HP. in an engine operating at a thermal efficiency of 25%, we must have $100 \div 0.25 = 400$ HP. supplied by the gas. One HP. equals to 33,000 ft. lbs. per minute, or $33,000 \times 60 = 1,980,000$ ft. lbs. per hour. But since one B.T.U. is equal to 778 ft. lbs., the number of B.T.U. required for one HP. hour $= 1,980,000 \div 778 = 2545$ B.T.U. per

hour. For 400 HP. per hour we need $2545 \times 400 = 1,018,000$ B.T.U. Since one lb. of coal produces about 30 cu. ft. of the gas, having a heating value of 300 B.T.U. per cu. ft., the quantity of coal required per hour is equal to: $1,018,000 \div (30 \times 300) = 113$ lbs.

3. The mechanical power developed in a stationary gas motor depends upon the size, number and arrangement of cylinders; normal speed; quality of fuel; also type and method of operation of the motor.

4. Using formulae (1) and (7), chapter VIII., the brake HP. per cylinder end equals to: $P = (24 \times 24 \times 30 \times 125) \div (21,875) - 0.75 = 98.0$ HP. In a two-cylinder double-acting engine, the total HP. at the brake equals to: $98 \times 4 = 392.0$ HP.

5. The B.T.U. required by the above engine per hour $= (392 \times 33000 \times 60) \div (778 \times 0.18) = 5,542,000$ B.T.U. Each gallon of oil generates $19,000 \times 6.5 = 123,000$ B.T.U. The oil consumption in gallons per hour equals to $5,542,000 \div 123,000 = 45$ gallons per hour.

6. With the tandem arrangement of cylinders there are fewer bearings and fewer duplicated parts, resulting in reduction of friction and a higher mechanical efficiency.

7. The "hit-or-miss" method of speed governing is more efficient than the "throttling" method, but it has the objection of an uneven distribution of power.

8. By scavenging the gas engine we increase the

effective volume of the cylinder and obtain a more perfect explosive mixture, which results in an increase of power output and a higher efficiency.

9. Back-firing is prevented in large gas engines by providing separate valve chambers for the gas and air, thus excluding the gas from the air until it is ready to enter the cylinder.

10. In the Diesel Motor the pure air is compressed in the cylinders and liquid fuel is injected, the heat for ignition being generated as a result of the air compression. This results in a maximum compression and high efficiency.

11. In order to utilize the gas motor for propelling submarines some means must be provided for supplying large quantities of air for combustion, and a special device has to be used for exhausting the burned gases.

12. The advantages in using gas motors instead of storage batteries for submarines are: The freedom from fumes, the greater power capacity of the gas motor, and a longer period of time permissible for independent trips.

CHAPTER X.

AUTOMOBILE MOTOR OPERATION.

By properly arranging a number of operating devices within the easy reach of the driver, the operation of all the parts of the automobile motor and its accessories, such as the transmission system, steering and brakes, are placed completely in his control. In this equipment are also included all the indicating instruments, lights, signals, switches, etc.

The various automobile operating devices can be classified as follows:

1. Devices for regulating **engine speed**:
 - (a) Throttle lever for fuel.
 - (b) Pedal for fuel control.
 - (c) Ignition control lever, for advancing or retarding the spark.
 - (d) Muffler by-pass control.
2. Devices for regulating **speed of car**:
 - (a) Speed control lever (gear shift).
 - (b) Clutch pedal.
3. **Braking** devices:
 - (a) Foot brake.
 - (b) Emergency brake.
4. Devices for controlling the **direction** of the car:
 - (a) Steering wheel and mechanism.

5. Indicating Devices :
 - (a) Air pressure guage.
 - (b) Electrical instruments.
 - (c) Speedometer.
 - (d) \Lubricator.
6. Switches :
 - (a) Cut-out switch for ignition.
 - (b) Light switch.
 - (c) Self-starter switch.
7. Signals :
 - (a) Horn.
 - (b) Lights.
8. Starting devices :
 - (a) Starting crank.
 - (b) Air starting equipment.
 - (c) Electrical starting devices.

Due to this great number of operating devices, the safe and efficient driving of a modern gas-motor vehicle demands all the attention of the operator and the exercise of all his physical senses, besides the constant use of his hands and feet while the car is in motion.

STARTING THE ENGINE.

Before starting the motor, all the parts should be carefully inspected to see that they work properly and that there are no loose connections. The lubricating system should be supplied with the proper amount of oil and grease, and the flow carefully adjusted. Then the gasoline tank is filled, and the

radiator tank supplied with water, after which the supply cock is opened, and the carbureter is flooded with gasoline. Next, the emergency brake is set, the ignition switch is closed, the spark is retarded, and the throttle valve is slightly opened. Care must be taken to have the speed control lever in the neutral position before the engine is started.

Since the motive power of the internal combustion gas engine depends upon the explosions of the gas mixture, which cannot take place until the movement of the piston produces the proper conditions in the cylinder and in the ignition circuit, the gas motor cannot be started by merely opening the throttle, but some other form of motive power must be used to begin the operation. This is accomplished either by employing a starting crank which is geared to the flywheel and is operated by hand, or the engine may be started by some independent source of power, such as compressed air or on an electric motor. This is more satisfactory, as the operator does not have to leave his seat to crank the engine, and this avoids the inconvenience of losing control of the engine and the danger of back-firing, often attended with the backward "kick" of the crank in case the engine is suddenly reversed on starting.

ELECTRICAL SELF-STARTER.

On automobiles equipped with a dynamo which generates electric current for lighting and charging purposes, the engine is usually provided with an

electrical self-starter, consisting of an electric motor which is automatically connected to the flywheel when the starter switch is closed. The motor is supplied with power from the generator circuit, and is equipped with a pinion which is normally out of mesh with the spur gear on the flywheel. When the motor circuit is closed, the current energizes an electromagnet which draws the pinion into mesh with the flywheel gear, thus turning the engine over until working conditions are established. As soon as the engine reaches normal speed, the driving pinion is automatically thrown out of engagement with the flywheel gear, and it remains out of mesh even when the motor circuit is still closed.

IGNITION CONTROL.

The mechanism for regulating the time of ignition consists of a **spark lever** which is connected to a shaft running concentric with the **Steering Post**, and which transmits the motion of this lever, by means of bell-cranks and links, to the commutator. This gives a direct method for advancing or retarding the spark, by changing the angular position of the commutator sectors.

GAS CONTROL.

The quantity of fuel supplied to the engine is regulated by means of the **throttle lever**, which is secured to a hollow tube surrounding the steering shaft. This tube is connected by proper link mechanism to the throttle valve located in the inlet pipe

leading to the admission valves of the cylinders, so that any movement of the throttle lever either partly opens or closes the gas-passage from the carbureter to the engine, and thus provides means for regulating the speed of the motor.

SPEED CONTROL.

The speed of the car is controlled by means of the **gear change lever**, usually placed at the right hand of the operator. This lever has one neutral position, from two to four forward speeds, and one reverse speed. The movement of this control lever is transmitted to the gear shifting lever which moves the slide gears located in the transmission case to their proper position for each particular drive. In case the planetary system of transmission is used, the speed is controlled by applying the proper brake bands and friction disc as outlined in Chapter IX.

THE STEERING SYSTEM.

The general principle upon which the design of the steering system in modern cars is based is illustrated in Fig. 72. In this system, the car always travels along the arc of a circle, having an imaginary center at (C), which is the point of intersection between the produced axis of the rear wheels (R) and the produced axis of the front wheels (F), at any angle. The position of the front wheels is controlled by the steering wheel, which transmits its motion by means of the steering shaft to a system of

steering gears. These gears actuate a **steering lever** connected to the arm of one of the **steering knuckles**, which are both attached to the same distance rod or

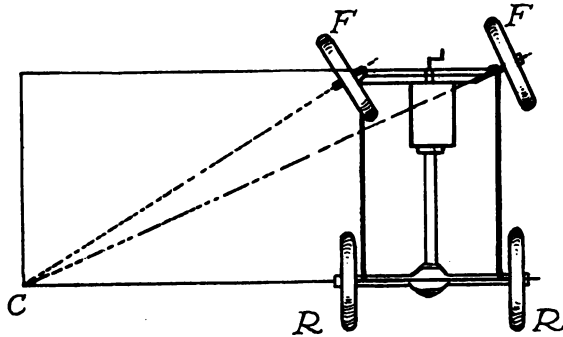


Fig. 72
The Steering System

connecting link, thus transmitting the motion of the steering lever to both front wheels.

SCREW AND NUT STEERING SYSTEM.

The gearing system which changes the rotary motion of the steering post to the proper movements of the steering lever, is frequently made up of the following mechanism: A screw thread is cut at the lower portion of the steering shaft upon which a threaded sleeve is raised or lowered by the rotary motion of the shaft, in the same manner as a nut may be moved along the thread of a fixed bolt, by

revolving the bolt and preventing the nut from turning. This is known as the **screw and nut** system, of changing from rotary to reciprocating motion. To this nut are attached, by means of pins, a number of links, transmitting this motion to a small shaft which carries the steering lever.

RACK AND PINION STEERING SYSTEM.

In some types of steering gears the motion of the sleeve traveling up and down the steering shaft is transmitted to the steering lever by means of a **rack and pinion**, as shown in Fig. 73. The sleeve, or nut (N), has an internal thread engaging the worm (W), which is rigidly fastened to the steering shaft (S). One side of the sleeve has a rack (R) attached to it, which meshes with pinion (P) connected to the operating lever (L). By turning the steering wheel, the sleeve is moved up or down the shaft. This movement is transmitted by the rack to the pinion which operates the lever. There are many other varieties of steering gears, but they all accomplish the same purpose of turning the front wheels a slight angle by a much larger angular motion of the steering wheel.

THE MECHANISM OF STEERING KNUCKLES.

The typical construction of a steering knuckle is shown in Fig. 74, where P represents the spindle and turning pivot, and A is the steering arm. The steering lever L is attached to either one of the

knuckles, depending upon the requirements of the particular type of machine. The spindle, pivot and

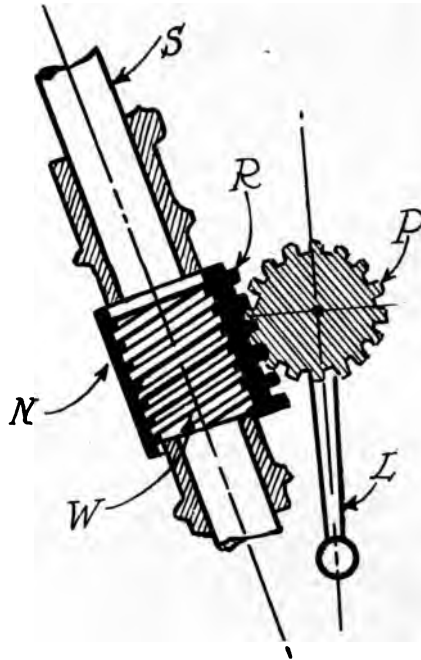


Fig 73
Rack and Pinion Steering Gear

steering arm are usually made in one piece to insure positive action on the wheels.

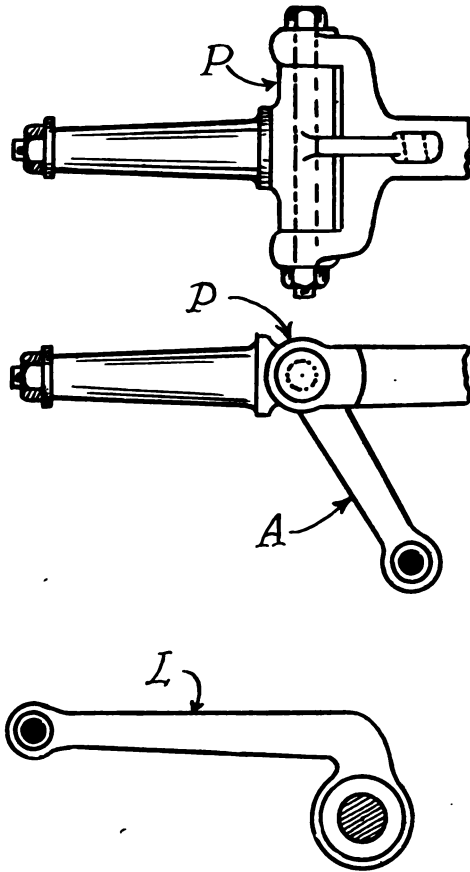


Fig. 74
The Steering Knuckle

THE BALL AND SOCKET CONNECTING LINK.

The two steering arms are joined by a connecting link which has a ball and socket joint at each end. These joints are usually made by having a short piece of steel tubing brazed on each end, and placing heavy spiral springs inside these tubes before the sockets are inserted. These sockets have flat surfaces pressing against the springs, the other sides being hollowed out, or concaved, to receive the ball joints located on the steering arms of the knuckles, or the ball joint at the end of the steering lever. This allows the free movement of the knuckles while at the same time their positive connection to the steering mechanism is maintained.

INTERNAL EXPANSION BRAKES.

The mechanical brakes used for stopping the car are usually located at the inner sides of the rear wheels, and they are controlled either by a hand lever placed near the speed control lever, or by pressing a pedal connected to the brake operating rods.

The internal expansion brake is similar in its construction to the internal expansion clutch, having a number of metal shoes which are pressed against the interior rim surface of the brake drum by the action of springs, toggle-joints, cams or eccentrics. These shoes are lined with some special soft material to provide for a gradual braking effect.

EXTERNAL EXPANSION BRAKES.

The external expansion type of brake is usually made in the form of a flexible metal band lined with leather, canvas, or special fireproof material, this band being tightened around the drum by the action of the brake rod and bell crank levers. Fig. 75 is an



Fig. 75
Automobile Brake
with "Raybestos" Lining

X-Ray drawing, showing the various parts of a modern automobile brake using a special fireproof lining, known as "Raybestos," for both the internal and external expansion brakes.

COUNTERSHAFT BRAKE.

In some cars there is provided an additional foot brake attached to the countershaft of the transmis-

sion system, which is applied in emergency cases to provide a positive method of stopping the motion of the car by preventing the driving shaft from turning. Care must be taken that the clutch is released before this brake is applied, to prevent serious injury to the transmission machinery.

BRAKE LINING.

In external expansion brakes the inside surface of the metal band is usually provided with a non-metallic lining, on account of the difficulty of properly oiling exposed metal-to-metal bearing surfaces. This lining must have a constant co-efficient of friction which is not affected by the action of oil, grease or water. Its fabric should possess enough mechanical strength to resist the high pressures to which it is subjected without becoming brittle, or charred from heat, and without its strands unraveling and working loose. The use of leather for this purpose is not very satisfactory on account of its inability to resist the heating effects of friction. The various inorganic fabrics containing asbestos are much better suited for brake lining since they are fireproof, and they do not contain any materials which may be decomposed or carbonized by the action of heat. In some brakes cork is used as lining with very good results, on account of its high co-efficient of friction and its natural elasticity which produces a gradual braking effect without overstraining the material. The importance of a proper material for automobile

brake lining cannot be overestimated when it is realized that the safety of the operator and his passengers depends upon the proper action of the brakes.

OPERATING TROUBLES.

The failure of the motor vehicle to respond to the action of any of its controlling devices is due either to some trouble developed in the motor, or in the transmission system, or in the mechanism connecting the various parts of the machine with the operating equipment. The common engine and transmission troubles were discussed in the previous chapters dealing with the various parts of the motor, such as the cylinder, fuel supply, ignition, lubrication, cooling, gearing, etc.

The various causes of failure to start the engine may be briefly summed up as follows:

- (1) Improper **explosive mixture**, due to obstructions in the gasoline or air supply systems, or presence of water and other impurities in the carbureter.
- (2) **Compression leaks** from the cylinder through valves, ports, ignition openings, or defective cylinder or piston walls.
- (3) **Ignition** troubles, due to loose connections, faulty spark plugs or weak battery.
- (4) Failure of the **lubricating** system, due to obstructions in the oil passages, overheating or improper supply of lubricants.
- (5) Failure of the **cooling** system, due to faulty

or weak circulating pump, disconnected fan, or obstructions in the piping.

(6) Break down of the transmission system due to broken gear teeth, connecting links and shafting, or worn out clutch and brake lining.

REMEDIES.

After the source of trouble is properly located, it is often possible to remedy the fault without much delay, providing the operator had the foresight to equip his car with the necessary repair tools, some duplicate parts and supplies.

In case the car does not pick up its speed in spite of the fact that the engine is operating with the throttle wide open, the trouble is usually due to the clutch failing to engage the driving shaft on account of lack of pressure or friction. This may be verified by stopping the engine and turning it over by means of the starting crank while the gear shifting lever is left in neutral position. If the clutch then remains stationary we may safely conclude that it is slipping. As a temporary measure, this may be improved by cleaning the clutch lining with gasoline, drying it thoroughly, and then lubricating it with castor oil, in case leather is used for lining; or by powdering the lined surface with rosin or any other adhesive material, to increase the friction between the two surfaces. To remedy this trouble more permanently, the clutch lining should be renewed, and all the working parts of the clutch

tightened up. The same treatment should be applied to a similar failure of the brakes.

In general, any makeshift repairs made in cases of emergency in the course of a trip must not be left for permanent use, but the faulty part should be either permanently repaired or entirely renewed at the first opportunity, to avoid a more serious breakdown in the future.

QUESTIONS ON CHAPTER X.

1. What equipment is required for an electric self starter system?
2. What is the function of the spark lever and how does it operate?
3. Name the advantages and disadvantages of controlling the speed of the car by means of the throttle lever.
4. What is the principle of operation of the screw and nut steering gear?
5. Name the principal parts of the steering mechanism having a rack and pinion type of gear.
6. Compare the construction of the internal and external expansion brakes.
7. Find the force in pounds that must be applied at the surface of a 12-inch brake drum to absorb the power of a 20 HP. motor, if the average speed of the wheel to which this brake is attached is 300 revolutions per minute.
8. Name the proper qualities of a material suitable for use as brake or clutch lining.

9. What is the proper method for starting an automobile gas motor?
10. Enumerate briefly the common operating troubles of the gas-driven automobile.
11. What is the effect of a slipping clutch?
12. How can the gripping power of a clutch be temporarily increased?

ANSWERS TO QUESTIONS ON CHAPTER IX.

1. Using formula (2), Chapter IX, we have in this case: $D = 10$ inches, $R = 1200$ r.p.m. and $V = 10 \times 1200 \times 0.2618 = 3141.6$ ft. per minute. This speed is excessive for ordinary gears, and calls for special material, or a larger wheel.

2. Referring to formula (3), Chapter IX, the tooth velocity (V) is here equal to 3141.6 ft. per minute, and HP. = 20. The tooth pressure is therefore equal to:

$$(20 \times 33,000) \div 3141.6 = 210 \text{ Lbs.}$$

3. The speed of the countershaft can be computed by using formula (4), Chapter IX, where $R = 1200$, $n = 20$, $N = 24$. Then the speed (r) of secondary shaft = $(1200 \times 20) \div 24 = 1000$ r.p.m. With gears 3 and 10 meshing (see Fig. 68), the speed of the driving shaft = $(1000 \times 18) \div 20 = 900$ r.p.m.; with gears 4 and 9 in mesh, the driving shaft has a speed of $(1000 \times 12) \div 24 = 500$ r.p.m.; with gears 5 and 8 in mesh, the driving speed is $(1000 \times 9) \div 30 = 300$ r.p.m. The reverse speed is equal to:

$(1000 \times 9) \div 30 = 300$ r.p.m. The range of speeds with this transmission is, therefore, as follows:

- (1) Direct drive, or high speed—**1200 r.p.m.**
- (2) Second speed—**900 r.p.m.**
- (3) Third speed—**500 r.p.m.**
- (4) Fourth, or low speed—**300 r.p.m.**
- (5) Reverse speed—**300 r.p.m.**

4. By reducing the velocity of the gear teeth in the worm gear system we are able to overcome large resistances by exerting relatively small forces, applied at the operating lever of the worm. (See Formula (5), Chapter IX.)

5. The planetary gear transmission system is simple in construction and operation; the slide gear system requires a more expansive equipment, but it has a greater range of speeds and can transmit a greater amount of power without overstraining the material.

6. The differential gearing system transmits the power from the driving shaft to the rear wheels in such a manner that each wheel can revolve at a speed required by the conditions of the road or direction of travel, independent of the other one.

7. The force which must be resisted at the wheels equals to 450 lbs. since the car weighs just one ton. The distance traveled by the car per minute = $(20 \times 5280) \div 60 = 1760$ ft. per min. Since the HP. equals to the total number of ft. lbs. per minute, divided by 33,000, the power required at the wheels

$$450 \times 1760 \div 33,000 = \mathbf{24\ HP.}$$

8. Assuming a friction loss in the transmission system of 30%, with a longitudinal shaft drive, the HP. delivered by the engine at the clutch is equal to: $24 \div 0.7 = \mathbf{34.3 \text{ HP.}}$

9. With a mechanical efficiency of 85%, the power developed in the motor is equal to: $34.3 \div 0.85 = \mathbf{40.4 \text{ HP.}}$

10. Assume a single acting, four cycle type of engine, having four vertical cylinders. The HP. at the clutch = 34.3. Using the power formula for automobile engines we have: $4 \times d^2 \div 2.5 = 34.3$, where d is the diameter of bore in inches. Therefore $d^2 = (34.3 \times 2.5) \div 4 = 21.44$ sq. inches. This calls for a diameter of 4.6 inches, or about $\mathbf{4\frac{5}{8} \text{ inches.}}$ Using a ratio of stroke to diameter of 1.25, the length of stroke is equal to: $4.6 \times 1.25 = 5.75$, or $\mathbf{5\frac{3}{4} \text{ inches.}}$

11. The various types of clutches used for gas-driven automobiles are: The bevel clutch, internal expansion, external, multiple disc, Hydraulic and Magnetic.

12. Before shifting the gears to change speed, the clutch should be released and the gear shifting lever moved gradually to the position for the desired speed.

CHAPTER XI.

MOTOR REQUIREMENTS FOR AVIATION.

By the term "aviation" is understood all artificial flight by means of heavier-than-air machines, such as aeroplanes, in which the lifting power as well as the forward motion is supplied by a motor.

In the lighter-than-air flying machines, such as dirigible balloons, the motor is used only to propel it forward, since its lifting power is supplied by the proper volume of a very light gas which displaces an equal volume of air, the airship being lifted in the same manner as a body immersed in a liquid is forced upward by a pressure equal to the weight of the liquid displaced.

In order to clearly understand the special requirements of gas motors used for aviation, it is necessary to have a general idea of the action of an aeroplane, and of the forces generated by the motor which are necessary to lift the total weight of the machine and to drive it in any direction at the required speed.

FUNDAMENTAL PRINCIPLES OF AVIATION.

Whenever any portion of the surface of a body is exposed to the action of air moving against it, this creates a pressure acting upon the exposed surface

due to the velocity of the moving air, providing the body is prevented from moving with the same velocity. The amount of pressure generated by the moving air depends upon its **velocity**, the **area** of the exposed surface, and the **angular position** of this surface with respect to the direction of the motion of the air. It was found from many experiments that if a flat surface be kept stationary at right angles to a current of air, the total pressure acting upon this surface will equal to:

$$P = A V^2 \div (300) \dots\dots\dots (1)$$

Where P is the total pressure in pounds, A is the area of the exposed surface in square feet, and V is the velocity of the moving air in miles per hour.

In case the flat surface, usually called a **plane**, is inclined to the direction of the moving air at any angle less than 30 degrees, then the pressure acting upon this plane is reduced in the ratio of this **angle of inclination** (in degrees) to 30°, on account of the fact that at these small angles some of the air particles are deflected by the plane from their original path, thus reducing their velocity and changing their impact from the original direction to one at right angles to the position of the plane. Fig. 76 shows the direction of flow of air particles moving against the plane surface BC inclined at an angle (a) to the direction of the velocity of the air (V). The total pressure created by this velocity in the direction of air motion is indicated by letter (P) (see Fig. 76) and this is known as the **equivalent pressure** due to

velocity. The resultant pressure acting at right angles to the surface of the plane, marked by letter (N), is known as the **normal pressure**, and its relation to the equivalent total pressure for any angle of inclination less than 30 degrees may be expressed as follows:

$$N = (P \times a) \div 30 \dots \dots \dots (2)$$

Where **N** is the normal pressure, **P** is the total pressure corresponding to any air velocity, and **a** is the

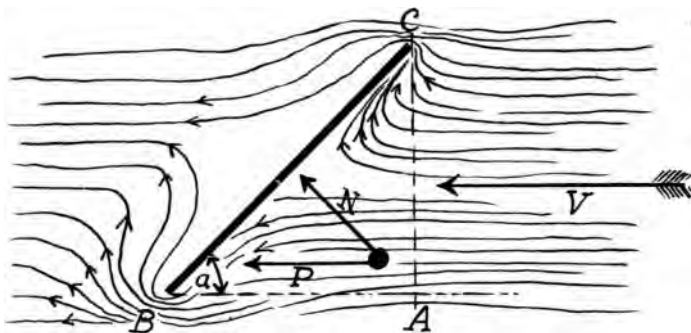


Fig. 76

Air Pressure on Inclined Plane

angle between the direction of air velocity and the edge of the inclined plane, in degrees.

For an angle of inclination greater than 30 degrees, the normal pressure is practically equal to the equivalent pressure, or

$$N = P \dots \dots \dots (3)$$

Since the normal pressure upon a plane due to a certain air velocity is produced by the relative motion of the air against the stationary plane, the same result can be obtained by having the air practically stationary, and moving the plane against the resistance of the air with the same velocity that was assumed for the moving air. This motion of the plane against the resistance of the air is accomplished in the aeroplane by means of a **propeller**, which is a device having curved blades and being revolved by the motor at high speed in such a manner as to impart a velocity to one or more inclined planes to which it is attached. This velocity produces a normal pressure acting at right angles to the moving surface as indicated in Fig. 77, where **R** is the aeroplane propeller driven by motor **M** and imparting a velocity **V** to the plane **BC** inclined at an angle **a** to the direction of the forward motion of the machine. The normal pressure upon the moving plane is indicated by the arrow marked **N** (see Fig. 77), at right angles to the plane.

The effect of this normal air pressure acting against the surface of the moving plane is to produce two component forces at right angles to one another, one force being in opposition to the motion of the plane, and known as the **drift**, and the other force acting at right angles to the drift and termed the **lift** of the plane. Referring to Fig. 77, the value of the drifting force corresponding to the normal pressure **N** is represented by arrow **D**, and the lift is indi-

cated by arrow L . The values of these two forces depend upon the amount of the normal pressure, as well as upon the angle of inclination (a). For any given angle (a), the ratio of lifting force to normal pressure is equal to the ratio between the horizontal projection AB (see Fig. 77) and the length of the edge of the plane BC . This ratio which depends

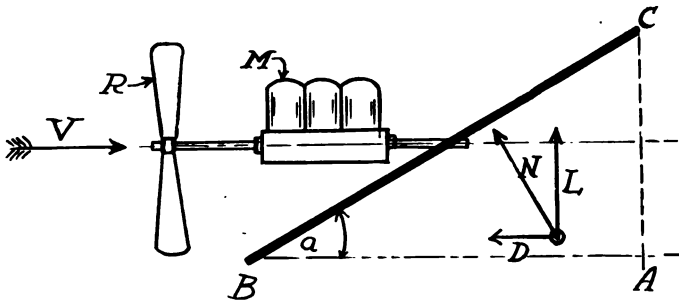


Fig. 77
Forces acting on Aeroplane
to its Velocity

upon the size of the angle a is usually termed the **cosine** of angle a , abbreviated **Cos a** .

The ratio of the drifting or retarding force to the normal pressure is equal to the ratio between the vertical projection **AC** (see Fig. 77) and the length **BC**, which ratio is known as **sine** of angle a , written **Sin a** .

These relations of the forces acting upon the aeroplane can be expressed in the following manner:

$$L = N \cos a \dots\dots\dots (4)$$

$$D = N \sin a \dots\dots\dots (5)$$

Where **L** is the value of lifting force in lbs. per sq. ft.,
D is the value of retarding force in lbs. per sq. ft.,
N is the normal pressure acting against the surface
of the moving plane due to its velocity, and **a** is the
angle of inclination between the plane and the direc-
tion of its motion.

In this manner, by tilting the surfaces of the aero-
plane at the proper angle and moving it forward by
means of the propeller with sufficient velocity, we
can produce a sufficient lifting force due to this
velocity to overcome the total weight of the machine
and the passengers, and this force will hold the aero-
plane up as long as the propeller keeps rotating at
the proper speed. The retarding force or drift has
to be overcome by the forward thrust of the pro-
peller which receives its power from the motor.

Table No. 5 gives the values of lifting and drifting
forces acting upon an aeroplane at various angles of
inclination with a velocity of 50 miles per hour.
From this table it would seem, at first, that an angle
of inclination equal to 30 degrees would be the ideal
for aviation, since at that point the lift reaches a
maximum value of 7.21 lbs. per sq. ft. But we note
that the drift increases still faster with the rise in
the angle, so that the ratio of the lifting force to the
retarding force is much greater at the smaller angles
of inclination, being equal 1.73 at 30 degrees, while

Values of Lift and Drift at various angles of an Aeroplane having a velocity of 50 m. per hour.

Angle of Inclination	Normal Pressure Lbs. per Sq. Ft.	Lift Lbs. per Sq. Ft.	Drift Lbs. per Sq. Ft.	Ratio of Lift to Drift
5	1.39	1.39	0.121	11.43
10	2.78	2.74	0.483	5.67
15	4.16	4.02	1.080	3.73
20	5.55	5.21	1.91	2.75
25	6.94	6.29	2.93	2.14
30	8.33	7.21	4.16	1.73
35	8.33	6.81	4.77	1.43
40	8.33	6.39	5.35	1.19
45	8.33	5.89	5.89	1.00
50	8.33	5.35	6.39	0.84
55	8.33	4.77	6.81	0.70
60	8.33	4.16	7.21	0.58
65	8.33	3.52	7.55	0.47
70	8.33	2.85	7.81	0.36
75	8.33	2.16	8.05	0.30
80	8.33	1.45	8.19	0.18
85	8.33	0.73	8.30	0.09
90	8.33	0.00	8.33	0.00

Table No. 5
Compiled by M. Kushlan

at an inclination of 5 degrees the ratio of lift to drift is 11.43.

This is the reason why aeroplanes are usually operated at about 5 degrees inclination after the machine has been lifted from the ground by using a larger angle.

POWER REQUIREMENTS FOR AVIATION.

The total energy necessary for propelling an aeroplane with a certain velocity is equal to the product of this velocity and the total retarding force or drift which is overcome by the action of the motor, if we neglect all the losses due to the slip or lost motion at the propeller, also friction losses, and the losses in energy due to the work absorbed by the air which is pushed backward and downward by the action of the propeller and the moving planes. If we represent the velocity of the aeroplane by letter V, and the drift by D, then the total work required to drive each square ft. of the aeroplane per minute will equal to $(V \times D)$, where V is velocity in feet per minute, and D is the value of drift in pounds per square foot of exposed surface. If V is in miles per hour, then the foot-pounds of work required for each sq. ft. of surface per minute is equal to $(V \times 5280 \times D) \div 60$, since there are 5280 feet per mile, and 60 minutes per hour. The theoretical HP. required for propelling each sq. ft. of an aeroplane is, therefore, equal to:

$$\text{HP.} = (V \times D \times 5280) \div (60 \times 33000) = (V \times D) \div 375 \dots \dots \dots (6)$$

Where V is the velocity of the machine in miles per hour, and D is the drift in lbs. per sq. ft.

Since the value of the drift depends upon the normal pressure, which varies as the square of the velocity, the power required to drive an aeroplane varies as $V^2 \times V = V^3$, or as the cube of the velocity. That means, that if we want to double the velocity of the machine we have to increase the size of the motor eight times; and to increase the speed three times, we must enlarge the motor about 27 times. The additional weight required for a larger motor soon eliminates the advantage gained by obtaining a greater lifting force due to the increased velocity, so that the velocity of the aeroplanes is naturally limited by this factor.

Table No. 6 shows the theoretical power per sq. ft. required for propelling an aeroplane at velocities ranging from 5 to 100 miles per hour, with an angle of inclination of 5 degrees, assuming no losses. From this we find that with a velocity of 60 miles per hour, the lifting force is about 2 lbs. per sq. ft. and the theoretical HP. required is about 0.028 per sq. ft. Assuming that the total exposed area of the planes and all other parts of the machine is equal to 500 sq. ft. and allowing for 50% loss to the air, the brake HP. required for a motor driving the aeroplane at 60 miles per hour $= 0.028 \times 500 \times 2 =$ **28.0 HP.** and to drive the same machine at 100 miles per hour, the brake HP. must be: $0.129 \times 500 \times 2 =$ **129.0 HP.**

Power required for propelling an Aeroplane at various velocities, with an angle of inclination of 5 degrees.

Velocity Miles per Hour	Equivalent Pressure Lbs. per Sq. Ft.	Normal Pressure at 5° Lbs. per Sq. Ft.	Lift at 5° Lbs. per Sq. Ft.	Drift at 5° Lbs. per Sq. Ft.	Theoretical H. P. Required per Sq. Ft.
5	0.08	0.013	0.013	0.001	0.000013
10	0.33	0.055	0.055	0.005	0.00013
15	0.75	0.125	0.125	0.011	0.00044
20	1.33	0.222	0.222	0.019	0.0010
25	2.08	0.347	0.346	0.030	0.0020
30	3.00	0.500	0.499	0.043	0.0034
35	4.09	0.682	0.680	0.059	0.0055
40	5.33	0.889	0.886	0.077	0.0082
45	6.74	1.122	1.120	0.098	0.0118
50	8.33	1.389	1.383	0.121	0.0161
55	10.50	1.750	1.745	0.153	0.0224
60	12.00	2.000	1.994	0.174	0.0278
65	14.05	2.34	2.335	0.204	0.0354
70	16.33	2.72	2.715	0.235	0.0439
75	18.75	3.12	3.11	0.272	0.0544
80	21.33	3.55	3.54	0.310	0.0661
85	24.10	4.01	4.00	0.350	0.0794
90	27.00	4.50	4.49	0.392	0.0941
95	30.00	5.00	4.99	0.436	0.1105
100	33.33	5.55	5.54	0.483	0.1290

Table No. 6

Compiled by M. Kushlan

DIFFERENCES IN DESIGN OF AUTOMOBILE AND AEROPLANE MOTORS.

Until very recently, most of the aeroplane motors were designed by modifying the automobile engine so as to adapt it for the particular requirements of the flying machines. The most important changes that were found necessary in redesigning the automobile gas-motor for use in aviation are as follows:

(1) **Reduction of weight** to a minimum, consistent with strength and power output.

(2) Reduction of **length of stroke**, to minimize the weight per horse-power.

(3) Making all parts positive in their action and providing duplicate equipment to insure absolute **reliability**, or continuous action of the motor.

(4) Designing every part for **maximum efficiency** of the motor, regardless of cost.

(5) Making the operation of the motor as nearly **automatic** as possible.

(6) Adjusting the length of connecting rod, size of combustion chamber, and valve mechanism to provide for the **effect of higher altitudes** upon the cylinder compression and suction.

It was found, by actual tests, that as a result of the lower atmospheric pressures at high altitudes, the HP. output of an ordinary automobile gas motor is reduced in the following manner:

At 4,000 ft. above sea level. . . .15% reduction

At 7,000 ft. above sea level. . . .25% reduction

At 17,000 ft. above sea level. . . .50% reduction

This is due to decrease in the quantity of explosive mixture admitted to the cylinder per cycle, resulting in a lower compression. As a result of these special conditions of operation, the modern aeroplane gas motor was finally developed along entirely new lines, differing in many details of construction from the automobile engine, but preserving all the general features of its design and principles of operation. The designers of the latest types of aviation motors have mostly abandoned the vertical and horizontal-opposed types of engine, but are using the radial arrangement of cylinders, which are made either stationary or revolving around the fixed crank shaft. This saves weight and helps cooling.

Most of the modern aeroplane motors are of the four-cycle type, using gasoline or crude petroleum oil as fuel, and cooled either directly by air, or by a circulating water system in the same manner as in the automobile motor.

The carbureter is in many cases replaced by a direct fuel supply system, by means of an individual pump for each group of cylinders, thus eliminating all the carbureting troubles and the heavy and complicated manifolds.

Another departure from the automobile engine design is the method of operating the valves in aeroplane motors, which are usually not all mechanically controlled, but the inlet valves are mostly automatic, since the question of close speed control is here not so important; in some cases both the inlet and ex-

haust valves are combined in one double disk valve, to save weight.

The ignition system of the latest type of aeroplane motor has a duplicate generating equipment, consisting of a high tension magneto and a battery; also a multiple set of connections and spark plugs to insure continuous service. The use of the high tension magneto simplifies the connections and eliminates the induction coils, vibrators and condensers.

All the parts of the engine are very carefully machined to save weight and to insure positive action, since the cost of manufacturing the motor is of secondary consideration, the main provision being made in the design to insure lightness consistent with strength and reliability, since a break down of the motor is in this case fatal to both the flyer and the machine.

QUESTION OF WEIGHT.

The low weight HP. of the modern gas motor was the determining factor in adapting it universally for propelling modern flying machines. Various other forms of motive power were tried, some with more or less success on short flights; but none of those prime movers can compete with the recent high-powered aviation gas-motors having a weight of 2 to 3 pounds per horse-power.

The most successful steam power plant designed by Sir Hiram Maxim for driving an aeroplane, weighed about 9 lbs. per HP. This did not include the weight of coal and water supply, which would

make it impracticable to operate the machine at any considerable length of time without landing.

The same objection of excessive weight per HP. holds true with electric propulsion by means of storage or dry batteries, although several successful flights of short duration were made by the use of primary cells.

The weight of the modern aeroplane gas motor is usually reduced in the following manner:

(1) By cutting down the ratio of stroke to diameter;

(2) By increasing the number of cylinders and arranging them in such a manner as to reduce the size of the crank shaft and case;

(3) By using high-grade materials of construction such as cast and forged steel for the engine parts, copper jackets, aluminum cases and cylinder heads, etc., and machining the metal very carefully;

(4) By reducing the weight of valve parts and combining the inlet and exhaust valve;

(5) By eliminating the flywheel and muffler.

The recent developments along these lines have brought the aeroplane motor to its practical minimum weight per HP. so that the present efforts of designers are directed more towards rendering this motor more efficient and reliable.

RATIO OF STROKE TO DIAMETER.

In the automobile engine the length of stroke is governed by the requirements of the connecting rod,

which is made as long as possible in order to obtain a smoother distribution of power and to reduce the side pressure upon the cylinder wall when the connecting rod is at its maximum angle. A longer stroke also results in greater efficiency, since it permits of a more complete expansion of the gas. In the aeroplane motor the length of stroke is limited by the fact that for minimum weight per HP. the stroke should be nearly equal to the diameter of bore. Since reduction of weight is of prime importance for aviation motors, the ratio of stroke to diameter is in this case made very small, the two being nearly equal; and in some cases, the length of stroke is even smaller than the cylinder bore. The uneven torque resulting from the shorter stroke is overcome by using a greater number of cylinders. The side pressure on the cylinder walls due to the shorter connecting rod is reduced by offsetting the crank shaft as explained in Chapter III (see "Crank Shaft"). This also helps to improve the efficiency and power output of the motor.

NUMBER AND ARRANGEMENT OF CYLINDERS.

The **power output** of any gas motor varies as the **square** of the cylinder diameter, assuming an equal average piston speed of 1,000 feet and a mean effective pressure of 70 pounds per square inch. The total weight of the motor, including piston, crank shaft and case, varies as the product of the area of the cylinder times the length of stroke. But since the area of cylinder bore depends upon the square

of its diameter, and since in aviation motors the stroke is nearly equal to the diameter, the **weight** of the motor varies approximately as the **cube of the diameter**.

By making the size of the cylinder twice as large we, therefore, increase its power capacity four times; and we raise its weight about eight times; so that the weight per horse-power is nearly doubled by doubling the cylinder diameter. From this it follows that four 6 x 6 cylinders will weigh half as much as one 12 x 12 cylinder, although the power developed in both cases is nearly the same. By reducing the size of cylinders and increasing their number we can, therefore, materially reduce the weight per HP. in aeroplane motors. The number of cylinders is, however, limited by the decrease in motor efficiency and lessened reliability of action, with the reduction in their size. Low efficiency means more weight of fuel per HP., which minimizes the saving in weight per HP. obtained by using smaller cylinders. All these factors must be taken in consideration in deciding upon the number of cylinders best adapted for any particular machine.

The arrangement of cylinders at various angles around the crank shaft in the forms of V, X, fan-shape or radiating all around the shaft, is shown in Figs. 22, 23 and 24. This reduces the length of crank shaft and the size of the crank case, which results in a considerable saving of weight and material.

CRANK SHAFT CONNECTIONS.

By connecting the pistons of the radial cylinders to the crank shaft at opposing angles we obtain a more continuous form of power, which permits of reduction, or total elimination of the weight of the flywheel. This arrangement also results in a more uniform rotary torque and better conditions for lateral stability. The shorter length of connecting rods, made possible by their radial connection to the crank shaft also helps to reduce the weight of the motor, but the increased thrust upon the bearings due to a greater number of cylinders per bearing area calls for better material and more careful construction to provide for the additional stresses.

QUESTION OF CONTINUITY OF SERVICE.

To insure continuous service of the various parts of the motor, many of these parts are duplicated, and more than one method is provided for operating them, so that when one system breaks down the arrangement is made for using some other method of operating that part of the motor, so as to keep up the velocity of the machine necessary to overcome its weight and to move it forward, until a convenient landing can be made and the damage permanently repaired.

COOLING SYSTEM.

In aviation motors using the air cooling system, the cylinders are built with projections or ribs on

the outside, to increase the radiating surface. This is often supplemented by a fan, driven at high speed from the main shaft to increase the rate of air circulation. With air-cooled revolving cylinder aeroplane motors, the cooling fan is omitted, since the high speed of the cylinders provides sufficient circulation. In all aviation motors, the rate of cooling is greatly increased by the velocity of the air, especially at high altitudes, where the rate of heat radiation frequently becomes too rapid and results in a considerable loss of power output and lower efficiency.

With a water cooling system, the jackets are usually made of very thin steel, or of electrolytic copper sheets, to save weight and to provide a good radiating medium. The water is circulated by means of a circulating pump of either the rotary or centrifugal type, to insure positive action; and the radiator is built in such a manner as to provide means for circulation by the natural, or thermo-siphon process, in case the circulating pump should fail.

LUBRICATION.

Oil is supplied to the various bearing points by the positive, or forced-feed method, the oil circulating pumps being driven from the crank shaft. The splash oiling system is not practicable for aeroplane motors, on account of the change in horizontal position and even complete overturning of the machine, which would not permit of an equal distribution of oil by this method to all the cylinders. In some

of the revolving types of motor, the non-return forced-feed system of lubrication is employed, the oil being pumped to the bearings and allowed to escape to the air. This is wasteful, but more reliable, since it eliminates the danger of clogging up the lubricating system by the repeated circulation of the same oil.

SPECIAL HEATING COILS.

On account of the low temperatures encountered at high altitudes, the modern types of aeroplane motors are usually supplied with heating coils placed around the fuel and oil supply piping to overcome the difficulty of operating the motor at freezing temperatures. Similar coils are provided for warming the operator's compartment in machines designed for flying at high levels for any length of time. These heating coils are supplied with burned gases from the exhaust pipes and they act in this case as mufflers, partly deadening the roar of the motor peculiar to all aeroplane machines. The addition of heating coils tends to decrease the power output and efficiency of the motor, on account of the increased back-pressure created in these coils, but this loss is fully justified by the gain in reliability of service and the added comfort to the pilot.

SPEED REGULATION.

The gas motor is best adapted for running at constant speed, making it the ideal source of motive

power for aeroplanes, which are usually driven at nearly the same velocity. In most cases, the propeller is connected directly to the crank shaft of the engine; in fact, in the recent types of aviation motors, the propeller shaft and the crank shaft are made of one piece. This construction is used in the Mercedes-Renault V-type twelve-cylinder engine shown in Fig. 82. The crank shaft in this engine has a diameter of 60 mm. (millimeters) at its main portion, which is increased to 68 mm. at the end where the propeller is attached, to provide for the greater stress in material due to the centrifugal action of the propeller when running at high speed.

Whatever small variations of speed may be desired, can be obtained by controlling the size of opening of the fuel valves, or by adjusting the time of ignition so as to vary the cylinder compression.

The minimum speed of the aviation engine is limited by the drop in efficiency and the resulting decrease in the velocity of the aeroplane when the motor is operated at low speed, which velocity may not be large enough to overcome the total weight of the machine. On the other hand, the maximum velocity of the motor must not exceed the value at which the **peripheral speed** of the propeller blades becomes higher than 18,000 feet per minute, in which case the large stresses in the blades may cause them to be thrown off the shaft.

The peripheral speed of any revolving body is the speed of its extreme edges traveling in a circular

path. Thus, a propeller having a diameter of 8 feet, and driven at 500 revolutions per minute, has a peripheral speed at the tips of the blades of $8 \times 3.1416 \times 500 = 12,566.4$ ft. per minute. Now, if the engine speed were increased to 1,000 revolutions per minute, the blade velocity would reach a value of about 25,133 ft. per minute, which would probably break the blades, leading to disastrous results. This factor, therefore, limits the maximum allowable speed of the aeroplane motor.

THE EFFECT OF THE PROPELLER.

The surfaces of the propeller blades are curved in such a manner that the edge of each blade has the same shape and direction in space as the thread of a very large screw, somewhat larger in diameter than the actual diameter of the propeller. Such a curved body is usually said to have a **helical surface**, and in making one complete revolution through some non-yielding medium, the blades would move forward the full distance of the **pitch** of the large screw from which it originated, in the same manner as an ordinary screw moves forward the distance of its pitch when it is rotated in a stationary threaded nut. The pitch of the propeller is only a theoretical distance, which is never actually attained in practice, since the air is a yielding substance, and as result of this the propeller always slips back a certain amount at every revolution of the shaft. The relation be-

tween the actual and theoretical forward velocity of the propeller may be expressed by the formula:

$$V = R \times 60 \times (P - S) \div 5280 = R \times (P - S) \div 88 \dots \dots \dots (7)$$

Where **V** is the actual forward velocity of the propeller, in miles per hour, **R** is the number of revolutions per minute of the propeller shaft, **P** is the theoretical **pitch** in feet, and **S** is the **slip** per revolution, in feet.

The effect of the propeller slip is to reduce the actual velocity of the machine to about 70% of the theoretical value. The action of the propeller results also in a loss of energy to the air, due to the backward velocity imparted to the column of air which is pushed back by the blades at every revolution of the shaft.

In general, the active force, or **thrust** of the propeller varies as the square of the number of revolutions per minute. Since the power utilized in driving the plane varies as the cube of the revolutions per minute, the thrust per HP. varies inversely as the speed of the propeller shaft, all other things being equal.

That indicates that an increase in the speed of the propeller results in a decrease of its efficiency.

The weight that can be sustained by a certain horse-power transmitted to the propeller varies directly as its diameter, so that by making the propeller large enough, we can reduce the power necessary to lift a certain weight. It was calculated that

a propeller having a diameter of 200 feet would be powerful enough to sustain the weight of an average man, using his muscular power.

From the above it would be natural to conclude, that for greater effectiveness and efficiency, the aeroplane propellers should be made fairly large and driven at low speeds. But on account of the practical requirements of very high aviation velocities, especially for certain types of military aeroplanes, the propeller speeds of modern machines are usually high, which means that the diameters must be correspondingly decreased to prevent excessive peripheral speeds of the blades.

MOTOR RATING.

The general method of estimating the brake horsepower of a gas motor can be applied to aviation motors with certain modifications. If we assume an average piston speed of 1,000 feet per minute, and a mean effective pressure in the cylinder of 70 pounds per sq. inch, then we can use the same rule as for automobile engines, namely:

$$\text{HP.} = (d^2 \times n) \div 2.5 \dots \dots \dots (8)$$

Where HP. is the total horse-power output of the motor, at the brake, d is the diameter of cylinder bore in inches, and n is the number of cylinders.

On account of the larger compression values used in aviation motors, resulting in higher efficiencies, the actual ratings of a great number of these machines were compiled by Dr. Hele-shaw, which re-

sulted in a higher average rating, based on the diameter of bore, viz.:

HP. = $(d^3 \times n) \div 2$ (9)
where the letters have the same meaning as in formula (8).

In case the actual piston speed of the motor is either higher or lower than 1,000 ft. per minute, the rated HP. is increased or decreased in the same ratio.

EFFICIENCY.

Due to the losses in energy which is dissipated to the surrounding air, the total efficiency of the aviation gas motor is much lower than that of the automobile engine. The principal power losses in the aviation motor, from the fuel tank to the propeller, may be classified as follows:

1. Heat losses:

- (a) Incomplete combustion.
- (b) Low range of cylinder temperatures.
- (c) Incomplete expansion of gases.
- (d) Radiation.

2. Mechanical losses:

- (a) Compression leaks.
- (b) Back-pressure.
- (c) Friction.

3. Air losses:

- (a) Propeller slip.
- (b) Energy loss due to backward velocity of air imparted by propeller blades.

- (c) Energy lost due to downward velocity of air imparted to it by action of planes.
- (d) Friction of disturbed air.
- (e) Skin friction due to high velocity of the parts of the machine moving in the air.

As a result of these conditions, the air efficiency is usually only about 50% of the total power delivered by the motor to the propeller, with the most ideal conditions of flight, using an angle of inclination of about 5 degrees, and flying at an average speed of 40 miles per hour.

QUESTIONS ON CHAPTER XL

1. How does the velocity of an aeroplane affect its lifting power?
2. How does the total area of planes affect the lifting power of a flying machine?
3. Find the velocity required to sustain the total weight of 1,000 pounds in a machine having a net effective area of 300 square feet, flying with an angle of inclination of 5 degrees.
4. Find the net mechanical power and the thrust of the propeller required to maintain the velocity of the aeroplane specified in question 3.
5. Assuming an air efficiency of 60%, find the rated HP. and size of cylinders required for an eight-cylinder motor to drive the aeroplane specified in question 3.

6. What features of construction are employed to reduce the weight per HP. of aviation motors?

7. What are the principal requirements of modern aviation motors?

8. What are the speed limitations in the aeroplane motor?

9. How is the propeller efficiency affected by its diameter and speed?

10. Assuming an average value of propeller slip of 30%, what is the axial velocity of an aeroplane propeller having an eight-foot diameter with a six-foot pitch, and driven at 700 r.p.m.?

11. Find the peripheral velocity of the blades of the propeller described in question 10.

12. Find the approximate HP. rating of an aviation motor having sixteen 5-inch cylinders.

ANSWERS TO QUESTIONS ON CHAPTER X.

1. The equipment for an electrical self-starter consists of an electric motor; an electro-magnetic controlling device for connecting the motor to the flywheel, and a switch for starting the operation. The power is obtained from the dynamo, which is also used for battery charging and lighting purposes.

2. The spark lever regulates the time of ignition by moving the outer housing of the commutator forward or backward from its normal position, and thus advancing or retarding the spark.

3. By operating the throttle lever to control the speed of an automobile, we obtain a wider range of

- (c) Energy lost due to downward velocity of air imparted to it by action of planes.
- (d) Friction of disturbed air.
- (e) Skin friction due to high velocity of the parts of the machine moving in the air.

As a result of these conditions, the air efficiency is usually only about 50% of the total power delivered by the motor to the propeller, with the most ideal conditions of flight, using an angle of inclination of about 5 degrees, and flying at an average speed of 40 miles per hour.

QUESTIONS ON CHAPTER XI.

1. How does the velocity of an aeroplane affect its lifting power?
2. How does the total area of planes affect the lifting power of a flying machine?
3. Find the velocity required to sustain the total weight of 1,000 pounds in a machine having a net effective area of 300 square feet, flying with an angle of inclination of 5 degrees.
4. Find the net mechanical power and the thrust of the propeller required to maintain the velocity of the aeroplane specified in question 3.
5. Assuming an air efficiency of 60%, find the rated HP. and size of cylinders required for an eight-cylinder motor to drive the aeroplane specified in question 3.

6. What features of construction are employed to reduce the weight per HP. of aviation motors?

7. What are the principal requirements of modern aviation motors?

8. What are the speed limitations in the aeroplane motor?

9. How is the propeller efficiency affected by its diameter and speed?

10. Assuming an average value of propeller slip of 30%, what is the axial velocity of an aeroplane propeller having an eight-foot diameter with a six-foot pitch, and driven at 700 r.p.m.?

11. Find the peripheral velocity of the blades of the propeller described in question 10.

12. Find the approximate HP. rating of an aviation motor having sixteen 5-inch cylinders.

ANSWERS TO QUESTIONS ON CHAPTER X.

1. The equipment for an electrical self-starter consists of an electric motor; an electro-magnetic controlling device for connecting the motor to the flywheel, and a switch for starting the operation. The power is obtained from the dynamo, which is also used for battery charging and lighting purposes.

2. The spark lever regulates the time of ignition by moving the outer housing of the commutator forward or backward from its normal position, and thus advancing or retarding the spark.

3. By operating the throttle lever to control the speed of an automobile, we obtain a wider range of

speeds, but the efficiency of the motor is thereby reduced.

4. In the screw and nut steering gear, the turning of the steering wheel causes the threaded sleeve to travel up or down the steering post to which the screw is fastened. This motion is transmitted to the steering lever which operates the steering knuckles attached to the front wheels.

5. The principal parts of the rack and pinion steering gear are: the wheel, the post, the worm, sleeve and rack, pinion, operating lever, steering lever, arms and knuckles.

6. In the internal expansion brake the pressure is applied by means of metal shoes, which are forced against the inside rim of the wheel by the action of springs, toggle joints, levers, or eccentrics. In the external expansion type, the pressure is applied externally by a flexible band operated by means of a rod or lever.

7. The total energy delivered by a 20 HP. motor per minute is equal to $33,000 \times 20 = 660,000$ ft. lbs. The distance traveled per minute by the extreme points on the rim of a 12-inch brake at 300 r.p.m. is equal to:

$$12 \times 3.1416 \times 300 = 11,300 \text{ ft. per minute.}$$

The force applied at the brake is equal to:

$$660,000 \div 11,300 = \mathbf{58.4 \text{ lbs.}}$$

8. The qualities necessary for brake or clutch lining are: constant coefficient of friction; mechan-

ical strength, and resistance to the effects of heat. It must be nearly fireproof without being too brittle.

9. The following method of procedure should be carried out in starting an automobile gas motor: inspection, lubrication, gasoline supply, water supply, supply cock, carbureter, emergency brake, ignition switch, spark retarded, throttle valve opened, engine started.

10. The common operating troubles of the gas-driven automobile are: engine troubles, misfiring, engine running hot, slipping clutch, ineffective brakes, defects in transmission, tire troubles.

11. The effect of a slipping clutch is to reduce the speed of the car, or in severe cases this may cause the complete failure to transmit sufficient power from the motor to the wheels to move the car.

12. The holding power of the clutch may be temporarily increased by cleaning the clutch lining with gasoline, and inserting between the lining and the bearing surface of the wheel some substance that will furnish enough friction to transmit the power.

CHAPTER XII.

TYPES OF AVIATION MOTORS.

Up to the beginning of the twentieth century, the construction of aeronautical gas motors was hardly developed, except in its experimental stage, primarily, because actual flight by means of heavier-than-air machines was at that time in its very infancy, and secondly, on account of the many defects in the construction of the older types of automobile gas motors which were overcome only recently. When the phenomenal success of the **Wright** aeroplane had demonstrated to the world the great possibilities of aviation by utilizing the power of the gas motor, there was a sudden demand for improved types of gas motors designed along new lines, to meet the requirement of a concentrated form of mechanical power for propelling modern flying machines.

Naturally, the earliest types of aeroplane motors followed very closely along the lines of design of the automobile and marine gas engines, which were of the vertical type, having from four to six cylinders, with only a few modifications to reduce the weight and add to the reliability of the motor. It may be interesting to note that with all the recent wonderful achievements in the field of aviation motors the

standard vertical engine is still very prominent and is in successful use in many latest types of aeroplanes in the United States and abroad.

CONVENTIONAL FOUR-CYLINDER ENGINE.

As an illustration of a modern type of aeroplane motor, resembling in many respects the original four-cylinder vertical engine used for automobiles, may be mentioned the **Vivinus** aviation motor, shown in Fig. 78. The valves of this engine marked (V) are all mechanically controlled and are located in the cylinder heads. The crank shaft has attached to it at one end a pressed steel flywheel (F) punched with a great number of holes to save weight. The cylinders of this motor are water-cooled. The propeller (P) is fastened directly to the motor, to reduce transmission losses to a minimum. This motor is rated at 12.5 HP. per cylinder, giving a total normal output of 50 HP., the complete motor weighing about 300 lbs., or about 6 pounds per horse-power. Such a weight is above the average for modern aviation motors, but this engine has won for itself a reputation of high reliability and efficiency, and it was used for supplying motive power to the **Farman** biplane in England with great success.

In some of the more recent types of four-cylinder vertical aviation motors, the cylinders are air cooled, in which case it was found that on account of the higher pressures and temperatures developed in

aeroplane motors, the enlargement of radiating surface by means of ribs was not sufficient to carry away the intense heat, and it became necessary to

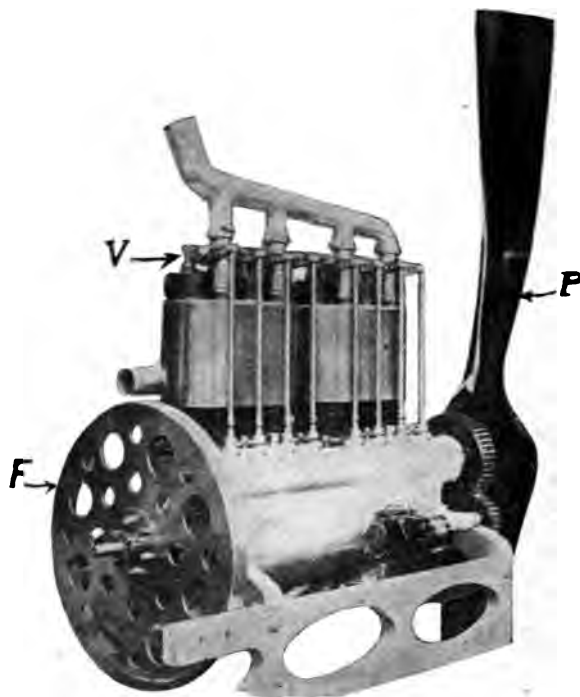


Fig. 78

Vivinus Four-Cylinder Aviation Motor

provide greater air circulation by means of a mechanically driven fan inclosed in a proper sheet metal housing.

THE SIX CYLINDER VERTICAL AVIATION MOTOR.

When the number of cylinders of an aeroplane engine is increased to six or more, the flywheel is often eliminated, and the effect of the propeller is utilized to supply a steady rotary motion to the crank shaft. In a two and four cylinder engine, the flywheel is usually required on account of the relatively long intervals between power impulses to the shaft; but with the greater number of cylinders, the power is more nearly balanced, since the explosions occur more frequently, and the inertia of the rapidly whirling propeller blades is then sufficient to insure a uniform torque and continuous operation of the motor.

As a typical example of one of the latest six-cylinder vertical motors used for propelling military aeroplanes, we have the **Benz** engine shown in Figs. 79 and 80, described in detail by Mr. E. H. Sherbondy in the "Gas Engine" magazine of November, 1917. This engine, and a twelve-cylinder motor of the Mercedes type, shown in Fig. 82, were shot down in France during the year 1917, and were given by Baron Charles Huard to Mr. Sherbondy, who made a careful study of their details after they were completely dismantled.

Referring to Fig. 79, which is a longitudinal view of the Benz six-cylinder aviation motor, the cylinders are made of cast iron, carefully machined, and the water cooling system consists of a continuous

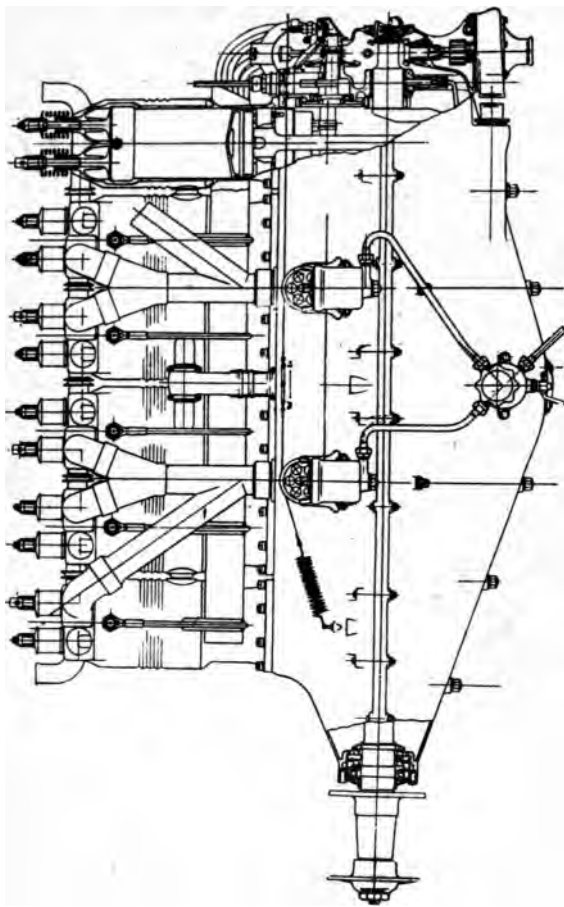


Fig. 79
Longitudinal View
Six-Cylinder Benz Motor

TYPES OF AVIATION MOTORS 311

jacket chamber welded on to the cylinders. The diameter of combustion chamber is about $5\frac{1}{2}$ inches (140 millimeters). The inlet and exhaust valves are all mechanically operated from the cam shaft by means of very light push rods and rocker arms, as shown in Fig. 80, which is a cross-section through the center line of one of the cylinders of the same engine. The fuel is supplied by means of a float-feed type of carbureter, and the products of combustion are exhausted directly into the atmosphere. Ignition is supplied by a high-tension magneto, and the entire ignition equipment is duplicated to insure continuous action. Positive lubrication is provided by means of a gear pump which forces the oil to the various bearing points under pressure of about 60 pounds per square inch. This oil pump has two auxiliary plunger pumps for drawing the fresh supply of oil from a large outside tank. The propeller is direct-connected to the main shaft and performs the additional function of a flywheel. The same type engine, having four 130 x 180 mm. cylinders, won the first prize in the Kaiser Prize Contest for aviation, when it developed 103 horse-power with a speed of 1,290 revolutions per minute.

HORIZONTAL OPPOSED TYPE.

Fig. 81 illustrates the **Call** gas motor, which is typical of the American horizontal-opposed engine adapted for aviation. This engine has four 6 x $5\frac{1}{2}$ opposed cylinders, each cylinder capable of develop-

All the parts of this motor are built of high-grade materials, the cylinders being of **vanadium** alloy iron, and the water jackets and cylinder heads made of a special aluminum alloy, known as **magnalium**, to save weight and still preserve the required strength. This results in a weight of only 2.5 pounds per HP. Some of the features of construction of the Call aviation motor are: the **splash-feed** oiling system; auxiliary exhaust ports to provide more effective **scavenging** of the cylinders, and the use of a **muffler** to deaden the roar of the motor.

V-TYPE MOTORS.

As a distinct departure from the conventional automobile engine, the V-type aviation motor holds at present the most prominent place, on account of the great saving in weight of connecting rods, crank shaft and crank case which is made possible by this arrangement. The great economy in space obtained due to the V-shaped position of the two rows of cylinders permits of an increase in the number of smaller sized cylinders, which is also a factor in lowering the weight per HP. developed by the motor. These advantages have been fully appreciated by the pioneers of modern aviation as demonstrated in the later types of the **Wright** and **Curtiss** engines, and this type of motor is now being universally employed for military machines designed to fly at high velocities, and therefore requiring a large number of cylinders.

The 12-cylinder V-type motor of the **Mercedes**

ing $22\frac{1}{2}$ horse-power at normal speed, giving a total rated output of 90 HP. The magneto (**M**) is located

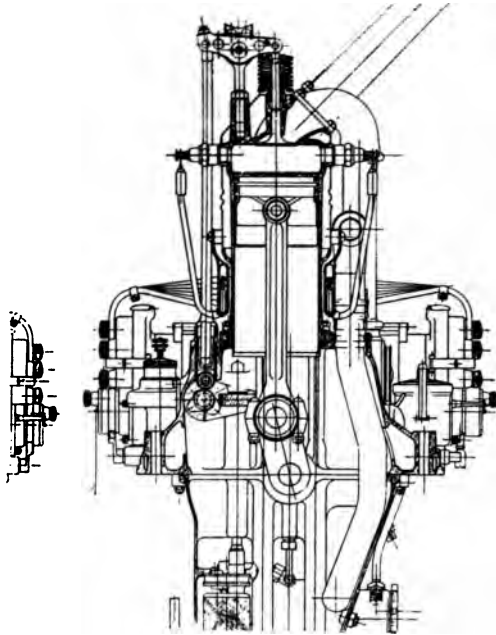


Fig. 80
Cross-Section
Six-Cylinder Benz Motor

at the center, and the valves (**V**) are all in the cylinder heads.

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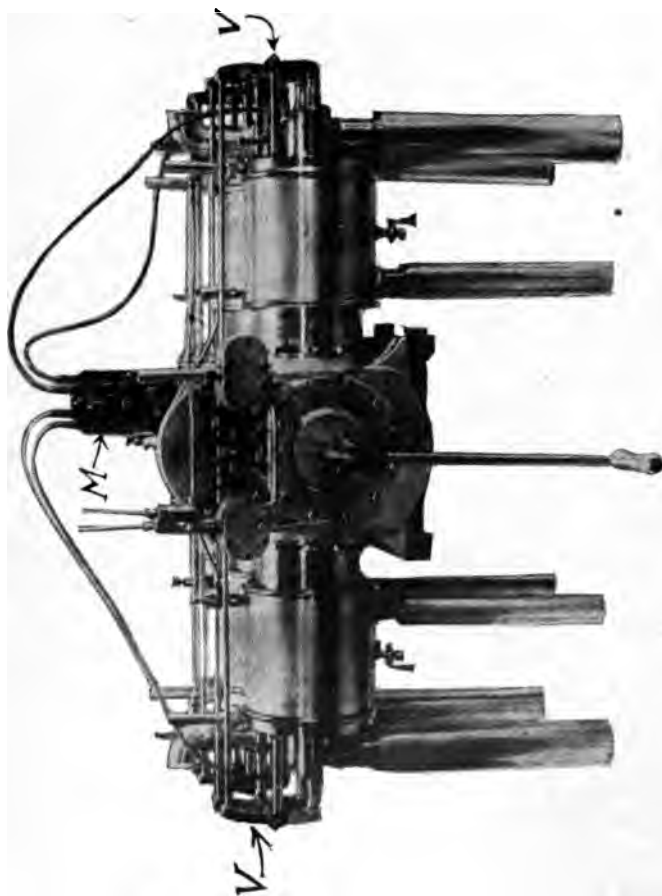


Fig. 81
Call Horizontal-Opposed Four-Cylinder Aviation Motor

type, built by **Renault**, is shown in Fig. 82, which is a cross section through the middle of one pair of cylinders. Some of the notable features of design of this motor are: the **symmetrical arrangement** of all the parts; the **overhead cam shafts** operating both valves of each cylinder; the duplicated **ignition** equipment; and the elaborate water **cooling system**.

Fig. 83 is a general view of the 16-cylinder **Antoinette** motor, which uses a system of fuel injection by means of individual plunger pumps similar to the method employed in the original **Diesel** gas motor. The inlet valves in this engine are automatically controlled by the suction created in the cylinders. The motor is water-cooled by means of copper jackets, and the speed is regulated by varying the quantity of fuel injected into the cylinders. This motor is rated at 100 HP. at normal speed.

THE WRIGHT MOTOR.

Among the earliest types of American aviation motors, the Wright engine is still considered to be one of the most reliable, safe and efficient machines, although the original Wright vertical engine weighed nearly 6 pounds per horse-power. This engine later gave way to an improved V-type 8-cylinder motor, known as the "Racer," rated at 60 HP. when running at 1200 revolutions per minute.

The Wright motor is made up of cast iron cylinders, of aluminum crank case and water jackets, nickel steel solid crank shaft and cam shaft. It has

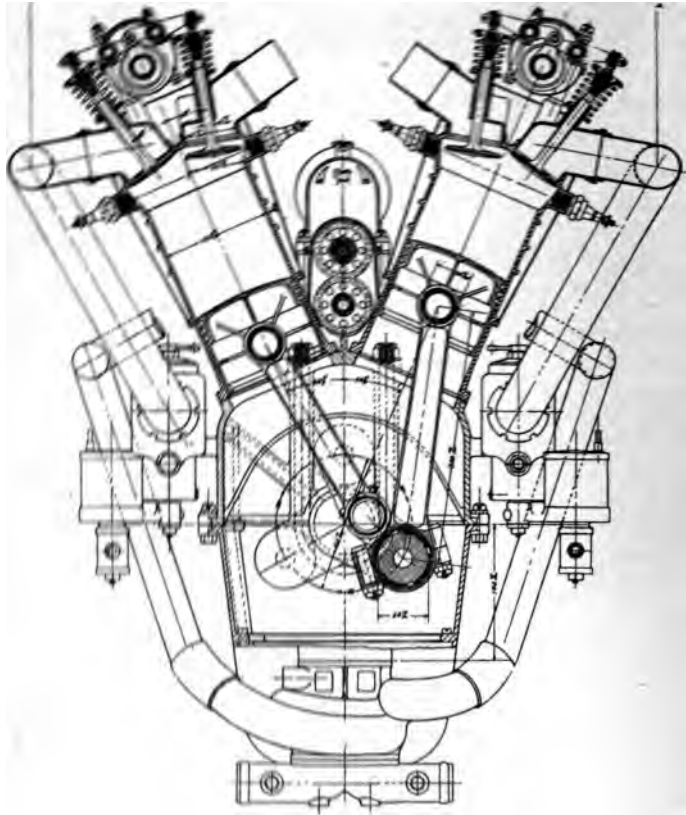


Fig. 82
Cross Section
Mercedes-Benz 12 cylinder Motor

no carbureter, the fuel being supplied directly to the mixing chamber by means of a small gear pump.

The ignition system consists of a high-tension magneto having a moveable field magnet which is arranged around the armature in such a manner that

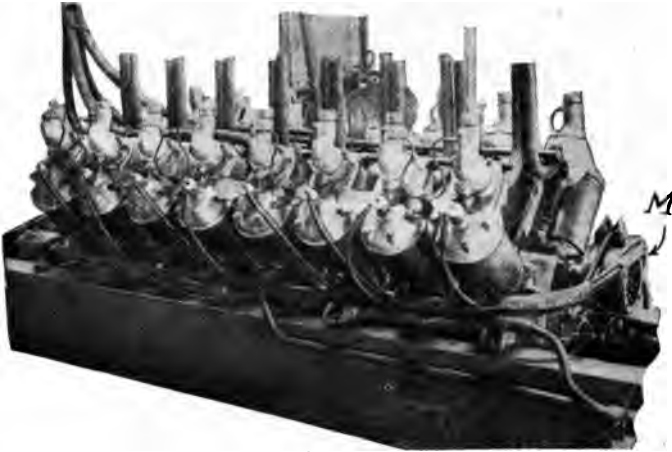


Fig. 83

Sixteen-Cylinder V-Type Antoinette Motor

it always gives the maximum current at any position of the spark. The water cooling system includes a centrifugal pump and a copper tube radiator.

The Wright engine is very popular in France, where it is manufactured in great quantities and it is known there as the Wright-Barriquand motor.

The enormous achievement of the Wright Brothers as pioneers of aviation may be appreciated from the fact that although their machine was the first

one to leave the ground under human control, yet with all the recent advancement in aeroplane motor construction, their original engine is still in a position to compete with the latest types of aviation motors.

THE CURTISS MOTOR.

One of the most successful V-type motors during the early stages of American aviation development was the 8-cylinder V-type Curtiss motor, rated at 50 horsepower. This engine was built along the lines of automobile motor design, only with a more careful selection of materials and a greater amount of machining, which brought the weight of this motor down to about 3.2 pounds per HP.

On account of the high compression employed in the Curtiss V-type motor, it is provided with an elaborate water-cooling system, including cylinder jackets and a radiator resembling in many respects the type used for cooling large automobile motors. The successful flights made by the early Curtiss V-type motors have demonstrated conclusively the advantage of this arrangement of cylinders for aviation purposes.

FAN-TYPE MOTORS.

In order to reduce the weight of the aviation motor still further and at the same time to obtain a balanced arrangement of cylinders, the **fan-type** and **star-type** motors were developed, particularly by the Italian and French builders. Among the Italian mo-

TYPES OF AVIATION MOTORS 319

tors of this type may be mentioned the **Anzani** and the **M. A. B.** engines, and among the French motors of the fan type we find the **Farcot**, shown in Fig. 84, and the **Pelterie** five-cylinder, air cooled motor.

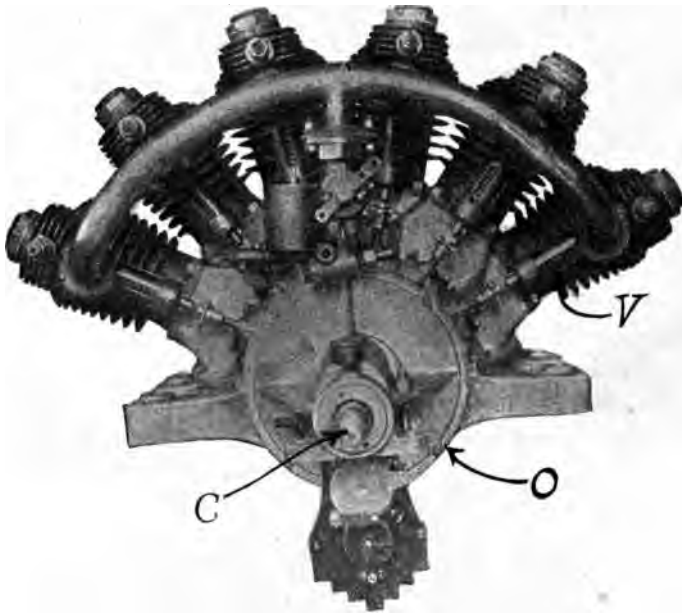


Fig. 84

Farcot Fan-Type Six-Cylinder Aviation Motor

Referring to Fig. 84, which illustrates the Farcot six-cylinder air cooled fan-type motor, the valves (V) are located at the sides of the cylinders which radiate from one side of the circular crank-case (C), forming the shape of a fan. This allows the use

of a very short crank shaft (s) and short connecting rods, which reduces the weight. The other advantages gained by this arrangement are: general smoothness of running, and regularity of power impulses to the crank shaft.

STAR-TYPE MOTORS.

As a natural step in the development of the radial type aviation motor, the **circular** or **star** type is employed in many European aeroplanes to provide for more perfect balancing with this symmetrical arrangement of cylinders. As a typical illustration of the star type engine, we might mention the 8-cylinder **Farcot** motor made up of two groups having 4 cylinders each, placed horizontally around the vertical crank shaft, each group being spaced symmetrically in a separate plane in such a manner that the result is an eight-pointed star with the cylinders spaced at 45 degrees from one another. The upper end of the vertical crank shaft has a fan attached to it, to provide a sufficient amount of air circulation for cooling.

The Farcot 8-cylinder star-type motor has the inlet and exhaust valves combined into one for each cylinder. The crank shaft is made hollow to save weight and to provide a path for circulating the oil to the various short connecting rods. This motor is made in three different sizes rated at 30 HP., 50 HP. and 100 HP., respectively, and the average weight per horse-power of these motors has been reduced to about 2.2 pounds.

TWO-CYCLE MOTORS.

In attempting to lower the weight of the aviation motor per horse-power, the two-cycle type of engine is employed in some cases on account of the increased power output of this engine with practically the same total weight of its main parts.

Theoretically, since the complete cycle of a "two-cycle" motor is accomplished in two strokes of the piston, the output of this type of engine should be about double that of a four-cycle engine having the same dimensions and operating conditions. But on account of the lower efficiency of the two-cycle motor, we actually obtain only about 40% increase in power while the quantity of fuel consumed is nearly doubled. This loss in efficiency, besides being wasteful of fuel, requires a greater weight of gasoline or fuel oil to be carried for a given length of flight, so that this added weight materially reduces the advantage gained by lowering the weight per HP. of the engine.

The best method for comparing the weights of aviation motors on the same basis is, therefore, to compute the **weight per horse-power hour**, which will then take into consideration the weight of the fuel as well as that of the parts of the motor. We will find, that based on the average weight per HP. hour, the advantage of the two-cycle over the four-cycle aviation motor is not as great as might at first be expected.

A typical two-cycle aviation engine was built by **E. W. Roberts** in two sizes, which were both successfully employed in many aeroplanes. This motor has three ports controlled by means of tubular rotary valves, which is a radical departure from the standard two-cycle motor design. Another important feature of the Roberts motor is the provision against the danger of suddenly reversing the direction of rotation, by using special ignition advance arrangement and a cellular by-pass from the crank case to the cylinder. The smaller size motor has four vertical cylinders, $4\frac{1}{2} \times 5$, water cooled, and develops 52 HP. at 1400 revolutions per minute, with a weight of 3.17 pounds per horse-power. The larger size motor consists of six vertical cylinders having a total output of 78 HP. at 1500 revolutions per minute, with a weight of 2.8 pounds per horse-power.

Among the American types of two-cycle aviation motors may be mentioned: the **Fox** motor, having an auxiliary fourth part used for scavenging purposes, and built in two sizes of 36 HP. and 200 HP., respectively. These motors have an average weight of 4 pounds per HP.

Another two-cycle motor of American make is the **Eldridge** four-cylinder vertical aviation engine, rated at 50-60 HP. at a maximum speed of 2000 R.P.M., having a weight of 2.5 pounds per horse-power. This motor was used successfully in many amateur flights in the United States.

ROTARY TYPES.

Many of the recent aviation motors are constructed with stationary crank shafts and revolving cylinders similar to the **Adams** rotary type of automobile engine, described in Chapter IV (see Fig. 24). The advantages gained by this method of construction are: the greater continuity and smoothness of operation without the use of a flywheel, and the high rate of air circulation, which gives a very efficient and simple cooling system. The valve mechanism and method of fuel supply are much simplified by the rotary cylinder construction. Some of the disadvantages of this type of motor are: the difficulty of properly lubricating the cylinders and excessive stresses in the cylinder material due to the effect of the centrifugal force.

X—FORM MOTORS.

Fig. 85 is an illustration of a **Gobron-Brille** eight-cylinder **X form** aviation motor which is also used for automobiles with a few slight modifications. The cylinders are arranged in this motor in four pairs, each pair of cylinders being attached to one leg of the X-shaped frame. One of the most remarkable features of construction of this motor is the location of the combustion chamber in the center, instead of in the head of each cylinder, which is provided with two pistons. The lower pistons are connected to the crank shafts by short rods, and the upper pistons are connected to the same shaft by long connecting

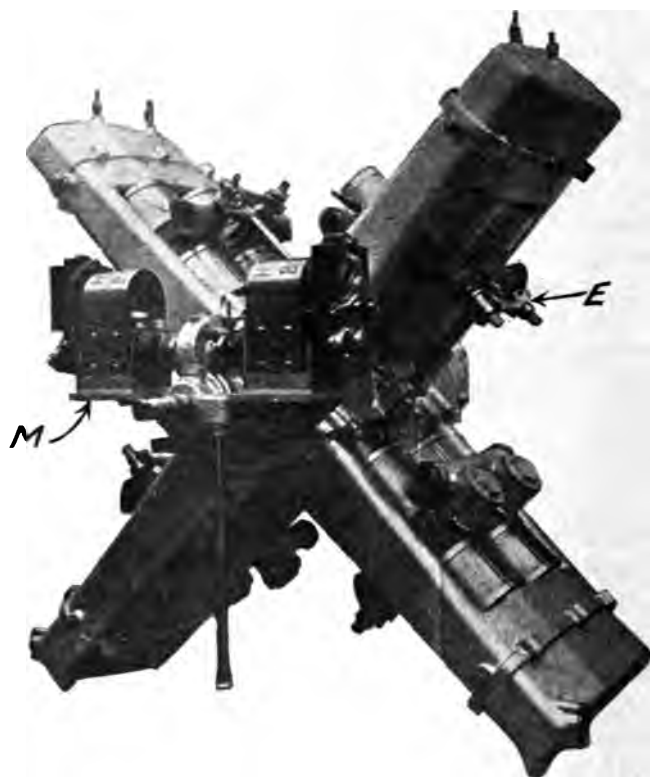


Fig. 85

Gobron-Brille' X-Type 8-Cylinder Aviation Motor

TYPES OF AVIATION MOTORS 325

rods passing outside of the cylinders. These rods are arranged in such a manner that at each explosion in the cylinder the two pistons are forced apart, transmitting their power impulses to the crank shaft.

The exhaust valves (E) are mechanically operated by means of double rocker arms and levers which are actuated by cams fastened to the cam shaft. The inlet valves are automatic. Ignition is provided by two high tension magnetoes (M) driven by worm gearing at right angles to the crank shaft.

The Gobron-Brille motor is water cooled by means of a circulating pump, the amount of cooling water required being very small on account of the peculiar arrangement of cylinders. It is rated at 75 HP. and weighs about 330 pounds complete.

GNOME REVOLVING CYLINDER MOTORS.

The Gnome revolving cylinder motor, shown in Fig. 86, is one of the most successful modern aeroplane engines of this type. This motor was employed by Weyman in a **Nieuport** monoplane when he won the 1911 Gordon-Bennett cup, and it was also used in many successful record flights such as from London to Paris, crossing the Alps, and many other endurance and altitude trials, which have fully demonstrated the high efficiency and reliability of this motor.

Referring to Fig. 86, which shows the seven-cylinder Gnome motor, the shaft (S) is stationary and

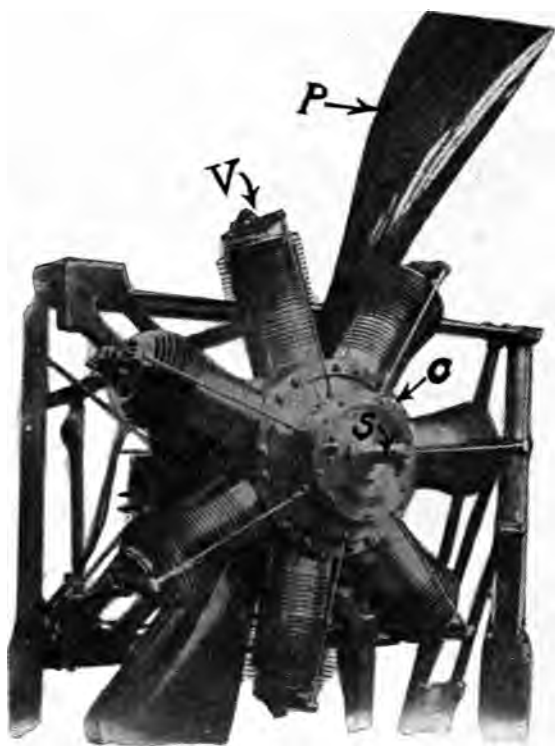


Fig. 86

Gnome Revolving Cylinder Aviation Motor

TYPES OF AVIATION MOTORS 327

made hollow to provide means for supplying fuel and oil to the revolving cylinders. The exhaust valves (V), placed in the cylinder heads, are mechanically operated by rocker arms. The inlet valves are located in the piston heads and are operated automatically by suction. All the valves are counterbalanced by heavy weights to offset the effect of centrifugal force. The arrangement of the connecting rods is similar to the same construction of the Adam-Farwell rotary motor. One master-rod acts directly upon the common crank-pin, and the other six rods are linked to it by means of intermediate levers.

In the fourteen-cylinder Gnome motor, the cylinder frames are arranged in two planes, seven in each plane, spaced in such a manner, that the entire revolving frame has the shape of a fourteen-pointed star, with the cylinder radiating at equal angles in all directions.

The propeller (P) is attached directly to the circular drum-shaped crank-case (C) as shown in Fig. 86.

This construction results in an **even, smooth running** of the motor, the elimination of the weight of a **fly-wheel**, and a perfectly **balanced** arrangement of moving parts. The air cooling system is fully adequate due to the high rate of air circulation around the ribbed cylinder walls, this rapid rate of cooling being at times excessive, which lowers the power output of the motor. Some of the disadvantages of the Gnome motor are:

(1) The requirement of employing the wasteful **non-return forced-feed** oiling system, which is the only method that can be relied upon to insure sufficient lubrication of the revolving parts.

(2) The waste of power used in overcoming the additional air resistance to the revolving frame, which results in a relatively high fuel consumption.

(3) The excessive stress in the material of the cylinders, caused by their high peripheral velocities at normal speed of the motor.

The standard Gnome motors are built in two sizes, one having seven cylinders, rated at 70 HP. and the larger one with fourteen cylinders, rated at 140 HP. The average weight of these motors is about 2 pounds per horse-power, which is practically the minimum for this type of gas motor.

THE SUNBEAM AVIATION MOTOR.

Among the several types of aeroplane motor employed for military purposes by the allied nations at the battle-fronts of Europe, the **Sunbeam** engine holds a very prominent place. Its chief advantages are: A very high degree of **reliability** due to an almost completely duplicated equipment; **flexibility** of size ranging from 100 HP. to 450 HP. by the use of the same model engine and varying the number of arrangement of cylinders; **adaptability** to widely varying operating conditions of climate, altitude, pressure, etc., and, finally, **standardization** of all parts, which are made interchangeable, to facilitate

manufacturing and repairs. This motor is manufactured in great quantities both in England and in the United States, the American engine being made by the Sterling Engine Company of Buffalo, N. Y., at the rate of about 130 per week, and by many large automobile concerns in all parts of the country.

The American Sunbeam engine has a cylinder bore of 4.725 inches, and a 5.118 inch stroke. The cylinders are made of aluminum provided with a steel sleeve at the bore. To insure continuous service, many parts of the motor are duplicated, each cylinder having two inlet valves and two exhaust valves, and each group of similar valves being operated from a separate cam-shaft.

One carbureter and one magneto are used for each group of three cylinders; and each cylinder is equipped with two spark-plugs. The 4-cylinder and 6-cylinder sizes are built as **vertical** types; the 8 and 12-cylinder sizes have the **V-type** arrangement; and the 18-cylinder size motor has the so-called **W-type** construction, the cylinders being spaced in three rows of six cylinders each.

No exact details of the Sunbeam engine are available at present on account of restrictions by the War Department.

THE LIBERTY MOTOR.

The sudden demand by the United States Government for a modern aviation engine of American design and manufacture that could favorably compare

with the European gas engines, to be used in military aeroplanes, found this country sadly behind times in gas-motor development, although the American inventive genius was largely responsible for the successful solution of practical aviation by means of employing the gas motor. As a result of a tremendous concentration of hard work combined with the best engineering skill that could be obtained in the United States, the **Liberty Motor** was finally produced in an astonishingly short period of 28 days, from the time the two engineers, C. J. Vincent of Detroit and E. J. Hall of San Francisco, sat down at their first conference in a room of Hotel Willard, to the final assembly of the motor when it was ready for the government test.

On account of the military importance of this motor there is very little information available as to the details of its construction. From the general description of the Liberty Motor used for military trucks and aeroplanes, as published in the "Journal of the Society of Automotive Engineers," for September, 1917, we can conclude that this engine embodies all the latest improvements in gas-motor design, particular stress being laid upon reliability of service and standardization of all parts.

The Liberty Motor is built in two types known as Class A and Class B, the latter being about 120 lbs. heavier than Class A engine, and both engines being of the same design, except having different sizes of cylinder bore. The lighter motor, rated at

TYPES OF AVIATION MOTORS 331

275 HP. weighs only 495 pounds, or about 1.8 pounds per horse-power, while the minimum reached by the standard European aviation motors is about 2 pounds per HP.

The Liberty Motor as used for aeroplanes is made in sizes ranging from 4 to 12 cylinders, and it is equipped with two independent ignition systems. It is designed to give full normal power only at low pressures actually encountered at high altitudes during operation in the air. It uses a full pressure lubricating system to insure a continuous positive oil supply, and all the parts are standardized and made interchangeable.

Some idea of the actual performance of the "Liberty" motor may be obtained from an account of a test of speed and endurance of this engine, published in the "Chicago Daily News" on November 17, 1917, entitled:

LIBERTY MOTOR SETS A MARK.

Ralph DePalma travels 633.12 Miles in 6 hours at Sheepshead.

This set the record of 105.6 miles per hour, as against the former average of 94.4 miles per hour.

This wonderful record of power capacity and endurance of the Liberty motor which was designed and built in such a short time, shows the great possibilities of American engineering skill and enterprise when aroused to their full power by an urgent national demand.

WEIGHTS OF STANDARD AEROPLANE MOTORS.

The comparative weights of standard types of aeroplane motors in pounds per horse-power are given in Table 7, which also contains their principal dimensions, normal speeds and HP. ratings. These values are only approximate, since they depend upon varying conditions of operation.

PRESENT LIMITATIONS.

A great many of the gas-motor problems have now been successfully solved, and most of the glaring defects inherent in the old types of the gas engine have almost been entirely removed. Still, we find ourselves at present with only a very crude method of converting heat into mechanical work, judging by the best thermal efficiencies that can be obtained with the latest types of gas motor, which rarely exceed 25%. That means that we are still wasting three-quarters of the heating value of the fuel in our most efficient form of engine. We have already pointed out the various thermal and mechanical defects of the present type of gas motor that contribute to these losses, such as: partial expansion, improper mixtures, low compression, incomplete combustion, back-pressure, limited range of temperatures, radiation and friction losses, etc.

With the advent of the special aviation gas engine we are confronted with new problems created by the peculiar conditions under which the aeroplane

DATA ON STANDARD AVIATION MOTORS

Name of Motor	Type	Dimensions (Inches)	Normal Speed— H.P.M.	H. P. Rating	Wt. per H.P. (Lbs.)
Wright.....	Vertical 4-cyl.	4½ × 4	1200	30-35	5.5—6
Curtiss.....	Vertical 4-cyl.	.....	1200	30	3.24
Wolseley.....	Vertical 4-cyl.	3¾ × 5½	1100	30	5.7
Wolseley.....	V-type 8-cyl.	3¾ × 5½	.....	60	4.6
Harriman.....	Vertical 4-cyl.	.....	1400	30-50	4.0
Green.....	Vertical 4-cyl.	4½ × 4¾	1100-1175	30-36	3.44
Green.....	V-type 8-cyl.	5½ × 5¾	1150	60	3.7
Hendee.....	V-type 8-cyl.	4 × 4½	.....	60-65	4.3
Roberts.....	Vert. 4-cyl. 2-cycle	4½ × 5	1400	52	3.17
Roberts.....	Vert. 6-cyl. 2-cycle	4½ × 5	1500	78	2.8
Pipe.....	V-type 8-cyl.	4 × 4	1200-1950	50-70	5.75
Maxim.....	Vert. 4-cyl.	5 × 5½	1400	87	2.54
Antoinette.....	V-type 16-cyl.	.....	.....	100	.....
Call.....	Horiz. Opposed 2-cyl.	.....	.....	45	3.0
Call.....	Horiz. Opposed 4-cyl.	.....	.....	90	2.5
Adams-Farwell.	Rotary 5-cyl.	6 × 6	1000	72	.....
Metz.....	Rotary 7-cyl.	6¾ × 6¾	800	125	3.0
Fiat.....	V-type, 8-cyl.	4.3 × 4.1	1700-2000	35-40	.....
Renault.....	V-type 8-cyl.	3.5 × 4.7	1500-1800	45-55	6.5
Farcot.....	Horiz. Circular 8-cyl.	.....	.....	30, 50, 100	2.2
Clement.....	Fan-type 7 cyl.	4.3 × 4.5	1200	50	3.8
Gobron-Brille..	X-type 8-cyl.	.....	.....	75	4.4
Gnome.....	Revolving, 14-cyl.	4.4 × 4.8	1300	100	2.2
Sunbeam.....	W-type, 18-cyl.	4.3 × 6.3	1800	475	3.36

TABLE No. 7

motor has to operate. The present difficulties of the aviation motor have been very clearly pointed out in a public address by Prof. W. F. Durand, of Leland Stanford University, on "The Aircraft Problem," in the following manner :

"Two or three problems not solved yet are of special importance. One is, supercharging airplane engines, the engine to be supplied with means to promote the maintenance of the power at high altitudes, and not suffer the loss normally attendant upon working in a rarified atmosphere; Another problem is modifying at will the pitch of the airplane propeller. It is of small use if the propeller is to maintain the same pitch in an atmosphere of reduced density; the engine will speed beyond the limit and the rotation speed of the engine will impose a limit upon the power which could be developed. Another is that of the spark plug. It is found that in the higher pressure of aeronautic service the spark plug based on automobile practice rapidly breaks down. The insulating characteristics are lost in one hour, or ten hours."

These problems are now being attacked by means of theoretical investigations and practical experiments, and upon the success of this work depends the future development of aviation.

FUTURE POSSIBILITIES.

The rapid progress in improving our means of communication accomplished by the practical ap-

plication of the gas motor for driving the many types of vehicles, vessels and flying machines has demonstrated the great future possibilities of this motor as a concentrated form of motive power. One method of improvement upon the present form of internal combustion engine is to raise the efficiency and method of control of the two-cycle engine so as to obtain the full benefit of its greater power output with a small sized cylinder. Another promising field of research and future experimentation is the practical development of the gas turbine on an efficient basis, which would greatly simplify the use of gas power especially for propelling aeroplanes.

With the reduction in the weight of storage batteries by an invention of some very light elements, the electrical drive of flying machines may again be taken up with successful results, which would do away with the complicated mechanism of the present types of gas motor. But whether the present type of gas motor will still further be improved, or whether it will be entirely eliminated by some other form of prime mover, it will always hold the distinction of having served as the chief factor in man's conquest of the air.

QUESTIONS ON CHAPTER XII.

1. Why were the early types of aviation motor built with vertical cylinders?
2. What is the most common system of lubrication employed in aviation motors?

3. What are the advantages of the V-type construction for aviation motors?
4. What are the chief points of superiority in the design of radial types of aviation engine?
5. Give the advantages and disadvantages of the two-cycle motor as used for aviation.
6. How is the length of stroke of an aeroplane motor affected by the arrangement of its cylinders?
7. What are the most notable features of construction of the Gobron-Brille X-form motor?
8. Enumerate the advantages of the rotary type of gas motor.
9. What are the chief disadvantages of the Gnome revolving-cylinder motor?
10. What are the main requirements of the modern gas motor used on military aeroplanes?
11. What is the arrangement of cylinders used in the 18-cylinder Sunbeam aeroplane engine?
12. Enumerate briefly the present limitations of the gas motor used for aviation.

ANSWERS TO QUESTIONS ON CHAPTER XI.

1. The lifting power of an aeroplane varies directly as the square of its velocity.
2. The lifting power also varies directly as the total area of the planes and of all the exposed parts of the machine.
3. To sustain the weight of 1,000 pounds with an area of 300 square feet, the lift per square foot must be: $1000 \div 300 = 3.33$ pounds. Referring to Table

No. 6, we find that with a velocity of 75 miles per hour, the lifting power is 3.11 pounds per sq. ft., and at 80 miles per hour the lift is 3.54 lbs. per sq. ft. The proper velocity is, therefore, about **80 miles per hour.**

4. The theoretical HP. required for the above machine is given in Table No 6, as 0.0661 per sq. ft. The net mechanical power delivered by the propeller in overcoming the air resistance is, therefore, equal to:— $0.0661 \times 300 = \mathbf{19.83 \text{ HP.}}$

The foot-pounds delivered by the propeller per hour = $(19.83 \times 33,000 \times 60)$; and the thrust equals to:— $(19.83 \times 33,000 \times 60) \div (80 \times 5280) = \mathbf{93 \text{ pounds.}}$

5. Assuming an air efficiency of 60%, the rated HP. of the above motor should be:— $19.83 \div 0.6 = \mathbf{33.05 \text{ HP.}}$

Using formula (9), Chapter XI, we have:

$33.05 = d^2 \times 8 \div 2 = 4d^2$. Therefore $d^2 = 33.05 \div 4 = 8.26$ sq. inches. This calls for a diameter of cylinder bore equal to **3 inches.**

6. The weight of aviation motors is reduced by making the stroke nearly equal to the diameter; by increasing the number of cylinders and decreasing their size; by arranging the cylinders for the minimum sizes of connecting rods, crank shaft and crank case; by eliminating as many parts as possible; and, finally, by employing high-grade materials, carefully machined.

7. The principal requirements of modern aviation motors are: lightness, reliability, efficiency, auto-

matic operation and interchangeable parts.

8. The minimum speed of an aeroplane motor is governed by the velocity required to sustain the total weight of the machine, and the maximum speed is limited by the peripheral velocity of the propeller blades.

9. The propeller efficiency varies directly as its diameter and inversely as its speed.

10. The actual velocity of the propeller having a 6 ft. pitch, driven at 700 r.p.m. is equal to: $6 \times 700 \times 0.7 = 2940$ ft. per minute.

11. The peripheral velocity of the blades of the 8 ft. propeller specified in question 10, is equal to $8 \times 3.1416 \times 700 = 17,600$ ft. per minute.

12. Using formula (9) Chapter XI, the power of an aviation motor, having sixteen 5-inch cylinders, equals to: $\text{HP.} = (5 \times 5 \times 16) \div 2 = 200$ HP.

ANSWERS TO QUESTIONS ON CHAPTER XII.

1. The early types of aviation motor were built with vertical cylinders on account of the similar construction used for the automobile and marine engine, from which the aeroplane motor originated.

2. The lubricating system most commonly employed in aviation motors is of the force-feed types, to insure a positive supply of oil and thus render the operation of the motor more reliable.

3. The V-type arrangement of the cylinders results in a shorter crank shaft and a lighter case.

4. The radial arrangement of cylinders gives a perfectly balanced and smooth operation, and a re-

TYPES OF AVIATION MOTORS 339

duction in weight of connecting rods, crank shaft and crank case.

5. The two-cycle aviation motor develops more power for a given size of engine, but it is less efficient.

6. The vertical or horizontal-opposed types of aviation motor permit of a longer piston stroke on account of the greater space provided for the connecting rods. With the radial spacing of cylinders the length of stroke is materially reduced.

7. The Gobron-Brille X-form aviation motor has a centrally located combustion chamber, with two pistons and two connecting rods per cylinder, the outer set of rods being longer than the inner set.

8. The rotary type of gas motor has a more uniform torque and a perfectly balanced operation. This construction gives a greater rate of cooling by air, and it eliminates the weight of a fan and of the fly-wheel.

9. The Gnome revolving-cylinder motor requires the use of a non-return oiling system, which is wasteful; it involves a considerable waste in power used to overcome the additional air resistance; and it introduces large stresses in the revolving cylinders.

10. The gas motor used on military aeroplanes must have a high degree of reliability; flexibility of size and adaptability to varying conditions of operation; also standardized parts which are absolutely interchangeable, to reduce the time of manufacture and repairs.

340 TYPES OF AVIATION MOTORS

11. The 18-cylinder Sunbeam Aeroplane engine has the **W-type** construction, the cylinders being placed in three rows, six in each row.

12. The present limitations of the aviation motor are:

(1) Reduction of the power output of the engine at high altitudes on account of the lower atmospheric pressures.

(2) The difficulty of modifying the pitch of the propeller according to the conditions of atmospheric density, to obtain nearly the same power and speed with varying conditions of the air.

(3) The weakness of insulation of the present type of spark-plug, which is not adapted for the high pressures and temperatures used in aviation motors.

THE END.

APPENDIX I.

USEFUL CONSTANTS AND FORMULAE.

1. Metric Conversion Factors.

Meters $\times 39.37 =$ Inches.

Meters $\times 3.281 =$ Feet.

Centimeters $\times 0.3937 =$ Inches.

Millimeters $\times 0.03937 =$ Inches.

Inches $\times 2.54 =$ Centimeters.

Ounces $\times 28.35 =$ Grams.

Kilograms $\times 2.205 =$ Pounds.

Liters $\times 0.2642 =$ U. S. Gallons.

Watts $\div 746 =$ HP.

Calories (Kilogram — degrees $\times 3.968 =$
B. T. U.

(Degrees Centigrade $\times 1.8$) $+ 32 =$ De-
grees F.

2. Measurement of Circular Bodies.

Circumference $= 3.1416 \times$ Diameter.

Radius $=$ Diameter $\times 0.5$.

Area of Circle $= 3.1416 \times (\text{radius})^2 =$
 $0.7854 \times (\text{Diameter})^2$

Area of Sector $= 0.008727 \times a \times (\text{rad-}$
 $\text{ius})^2$, where a is the angle of sector in
degrees.

Lateral surface of circular cylinder =
 $3.1416 \times \text{diameter} \times \text{height}.$

Area of each end = $0.7854 \times (\text{diameter})^2.$

Volume of cylinder = $0.7854 \times (\text{diameter})^2 \times \text{height}.$

3. Mechanical Equivalent of Heat.

1 B. T. U. = 778 Foot—pounds.

1 Ft. Lb. = 0.001285 B. T. U.

1 HP. = 33,000 Ft. Lbs. per minute.

1 HP. = 42.416 B. T. U. per minute.

4. Electrical Units (Direct Current Circuits.)

Volts = Amperes $\times$ Ohms.

Amperes = Volts $\div$ Ohms.

Ohms = Volts $\div$ Amperes.

W a t t s = Volts $\times$ Amperes = O h m s $\times$
 (Amperes)².

5. Rating of Gas Motors.

(a) General Formula:— $HP. = P \times L \times A \times N \div 33,000$, where HP. is the Horse-power per working cylinder end, P is the mean effective pressure per stroke, in pounds per sq. inch, A is the area of cylinder bore in sq. inches, L is length of stroke in feet, N is the number of revolutions per minute.

(b) Standard **Automobile** motor Formula:—
 $HP. = D^2 \div 2.5$ where D is the diameter of cylinder bore (in inches), assuming a Mean Effective pressure per cycle of 70

lbs. per sq. inch, and a piston speed of 1000 ft. per minute.

- (c) Average rating of **aviation** motors.

HP. = $D^2 \div 2$, assuming a piston speed of 1000 ft. per minute.

6. Aviation Formulae.

- (a) $P = A \times V^2 \div 300$ where P is pressure in the direction of velocity, in lbs., A in area of plane, in sq. ft., V is velocity in miles per hour.
- (b) $N = (P \times a) \div 30$ (for angles up to 30°); N = normal pressure, P = pressure in direction of velocity, a = angle of inclination.
- (c) $N = P$ (For angles larger than 30°).
- (d) Lift = $N \times \text{Cosine } a$.
- (e) Drift = $N \times \text{Sine } a$.
- (f) Theoretical HP. required = $(V \times \text{Drift}) \div 375$. Letters in formulae (c), (d), (e), and (f), have the same meaning as in (a) and (b.)
- (g) $V = R \times (P-S) \div 88$. V = velocity in miles per hour, R = revolutions per minute, P = pitch of propeller in feet, S = slip per revolution, in feet.
- (h) $\text{HP.} = V \times T \div 375$; or $T = \text{HP.} \times 375 \div V$. HP. = power transmitted by propeller, V actual velocity in miles per hour, T = thrust of propeller, in lbs.

APPENDIX II.

H.P. RATING OF GAS MOTORS (PER WORKING CYLINDER END) Compiled by M. Kushlan

Cylinder Bore (Inches)	AUTOMOBILE MOTORS					AVIATION MOTORS				
	Piston Speed in Ft. per Min.					Piston Speed in Ft. per Min.				
	800	900	1000	1100	1200	800	900	1000	1100	1200
2½.....	2.00	2.25	2.5	2.75	3.00	2.5	2.8	3.1	3.4	3.7
3.....	2.9	3.2	3.6	3.96	4.3	3.6	4.0	4.5	4.9	5.4
3½.....	3.9	4.4	4.9	5.4	5.9	4.9	5.5	6.1	6.7	7.3
4.....	5.1	5.8	6.4	7.0	7.7	6.4	7.2	8.0	8.8	9.6
4½.....	6.5	7.3	8.1	8.9	9.7	8.1	9.1	10.1	11.1	12.1
5.....	8.0	9.0	10.0	11.0	12.0	10.0	11.3	12.5	13.8	15.0
5¼.....	8.8	9.9	11.0	12.1	13.2	11.0	12.4	13.8	15.2	16.6
5½.....	9.7	10.9	12.1	13.3	14.5	12.1	13.6	15.1	16.6	18.1
5¾.....	10.6	11.9	13.2	14.5	15.8	13.2	14.9	16.5	18.2	19.8
6.....	11.5	13.0	14.4	15.9	17.3	14.4	16.2	18.0	19.8	21.6
6¼.....	12.5	14.0	15.6	17.2	18.7	15.6	17.6	19.5	21.5	23.4
6½.....	13.5	15.2	16.9	18.6	20.3	16.9	19.1	21.2	23.4	25.4
6¾.....	14.6	16.4	18.2	20.0	21.8	18.2	20.6	22.8	25.1	27.4
7.....	15.7	17.6	19.6	21.6	23.5	19.6	22.1	24.5	27.0	29.4
7¼.....	16.8	18.9	21.0	23.1	25.2	21.0	23.6	26.2	28.8	31.4
7½.....	18.0	20.2	22.5	24.8	27.0	22.5	25.3	28.1	30.9	33.8
7¾.....	19.2	21.6	24.0	26.4	28.8	24.0	27.0	30.0	33.0	36.0
8.....	20.4	23.0	25.5	28.0	30.6	25.5	28.7	31.9	35.1	38.3
8¼.....	21.7	24.4	27.1	29.8	32.6	27.1	30.4	33.8	37.2	40.5
8½.....	23.0	25.9	28.8	31.7	34.6	28.8	32.2	35.8	39.4	43.0
8¾.....	24.4	27.5	30.5	33.6	36.6	30.5	34.3	38.1	42.0	45.6
9.....	25.9	29.2	32.4	35.6	38.9	32.4	36.5	40.5	44.5	48.5

Note.—The above values were computed, assuming a Mean Effective Pressure for automobile motors of 70 lbs. per sq. inch, and for aviation motors M.E.P. = 87.5 lbs. per sq. inch.

TABLE No. 8

APPENDIX III.

GLOSSARY OF TECHNICAL TERMS.

Aeroplane or Airplane—Heavier than air flying machine operating by means of one or more planes moving against the resistance of the wind.

Angle of Inclination—The angle between the main planes and the direction of motion of an aeroplane.

Biplane—An aeroplane having two main planes.

B. T. U. (British Thermal Unit)—The quantity of heat necessary to raise one pound of water one degree Fahrenheit.

Calorie—Quantity of heat necessary to raise one kilogram of water one degree centigrade.

Calorific Value—The number of B. T. U. of heat that can be generated by the complete combustion of a unit weight of fuel under the most favorable conditions.

Carbureter—A device for vaporizing a liquid fuel and mixing it with the proper proportion of air.

Centrifugal Force—The effect of rotary motion upon the particles of the rotating body, tending to throw them away from the axis of motion.

Circumference—The curved line completely surrounding a circle.

Combustion—Burning of fuel with a proper supply of oxygen.

Component—A portion of the total force acting upon a body in a certain direction.

Compression—The pressure to which the gas mixture is subjected by the piston before it is exploded.

Cycle—A complete process, made up of a series of separate events which are repeated in the same order.

Density—Weight per unit volume.

Diameter—The distance between two opposite points on the circumference of a circle, passing through the center.

Drift—The force of air resistance opposing the forward motion of a plane.

Efficiency—The ratio between the output and input of energy in any part of a mechanical device.

Energy—Quantity of available work contained in a body.

Exhaust—The discharge of the products of combustion directly into the atmosphere or to a muffler.

Explosion—A rapid rate of combustion.

Flash Point—The temperature at which gasoline or oil vapor is ignited when the liquid is heated.

Force—Any natural cause that tends to change the physical state of a body from rest to motion, or from motion to rest.

Four-Cycle Engine—A gas motor in which the cycle is completed in two revolutions.

Gear—A toothed wheel, used for transmission of power.

Heating Value see **Calorific Value**.

Horse Power—The unit of power, equal to a rate of work of an average horse, which is taken as 33,000 ft. lbs. per minute.

Hydrometer—An instrument for measuring the specific gravity of liquids.

Ignition—The process of raising the temperature of a small portion of any substance to the point of burning.

Indicator Diagram—The diagram showing relation of pressures and volumes of the working fluid in the cylinder of any engine during a complete cycle.

Induction—Generation in any conducting material of electrical or magnetic energy due to the action of another circuit or magnet, through some insulating medium.

Inertia—The tendency of a body to continue its state of rest or uniform motion.

Internal Combustion Engine—Any engine in which the fuel is burned directly in the cylinder.

Lag—Angular retardation in circular degrees.

Lead—Angular advance in circular degrees.

Lever—A rod or link used for transmitting mechanical power.

Lift—The upward force upon a plane moving against the resistance of the air.

Mechanical Efficiency—The ratio between the energy developed in the cylinders and the mechanical power delivered by any engine.

Mechanical Equivalent of Heat—The mechanical energy necessary to generate one equivalent unit of heat. This is equal to 778 ft. lbs. per B. T. U.

Moment—The effect of a force, equal to the product of that force times its perpendicular distance from any given axis.

Monoplane—An aeroplane having one main plane.

Normal Pressure—A compressive force directed at right angles to a plane surface.

Parallel—Having the same direction as a given straight line.

Peripheral Speed—Linear velocity of the extreme points of a revolving body.

Perpendicular—Having a direction of right angles with reference to a given straight line.

Potential Difference—The difference in electrical pressure between two points, which generates the voltage.

Potential Energy—The amount of available work contained in a body due to its physical condition.

Power—The rate of performing mechanical work.

Pressure—A compressive force.

Radiation—Dissipation of energy through space.

Radius—The distance between the center and any point on the circumference of a circle.

Rating—The estimated horse-power output of an engine.

Resultant—The combined effect of all the forces acting upon a body.

Scavenging—Forcing the burned gases out of the cylinder by mechanical means.

Slip—Loss of velocity.

Specific Gravity—Relative weight of a unit volume of any substance as compared with the weight of the same volume of water.

Sulphation—The permanent formation of lead sulphate upon the surfaces of storage battery plates due to over-discharging.

Temperature—The intensity of heat, measured in degrees.

Thermal Efficiency—The ratio between the heat contained in the fuel and the energy developed in any heat engine by burning this fuel.

Torque—The moment of a force acting in a circular path described by any point of a rotating body.

Two-Cycle Engine—A gas motor in which the cycle is completed in one revolution.

Valve—A mechanical device for controlling the size of opening in a pipe or communicating passage.

Work—The product of a mechanical force and the distance through which it acts, usually measured in foot-lbs. or kilogram-meters.

INDEX

INDEX

A

	Page
Acids, sulphuric, specific gravities of (table)	129
Admission valves.....	67
Advancing and retarding the spark.....	141
Advancing and retarding the spark, effect of.....	19
Advantages of gravity supply system.....	32
Advantages of multiple cylinder engines.....	100
Aeroplane and automobile motors, differences in design.....	288
Aeroplanes, power required at different velocities (table)	287
Air and gas, explosive mixtures of.....	8
Air cooling system.....	169
Air supply	39
Answers to questions on Chapter I	48
Answers to questions on Chapter II	79
Answers to questions on Chapter III	104
Answers to questions on Chapter IV	149
Answers to questions on Chapter V	166
Answers to questions on Chapter VI	186
Answers to questions on Chapter VII	228
Answers to questions on Chapter VIII	257
Answers to questions on Chapter IX	275
Answers to questions on Chapter X	303
Answers to questions on Chapter XI	336
Answers to questions on Chapter XII	338
Anti-freezing mixtures.....	181
Arrangement of cylinders	82
Arrangement of cylinders in aviation motors.....	292
Arrangement of cylinders in stationary engines.....	200
Automobile and aeroplane motors, differences in design.....	288
Automobile motor operation.....	260
Automobile motor rating (table).....	344
Automobile motor transmission	231
Automobile troubles, operating, remedies for	273
Aviation, fundamental principles of.....	278
Aviation motors, continuity of service.....	294
Aviation motors, cooling system.....	294

•

—

INDEX

A

	Page
Acids, sulphuric, specific gravities of (table)	129
Admission valves.....\.....	67
Advancing and retarding the spark.....	141
Advancing and retarding the spark, effect of.....	19
Advantages of gravity supply system.....	32
Advantages of multiple cylinder engines.....	100
Aeroplane and automobile motors, differences in design.	288
Aeroplanes, power required at different velocities (table)	287
Air and gas, explosive mixtures of.....	8
Air cooling system.....	169
Air supply	39
Answers to questions on Chapter I	48
Answers to questions on Chapter II	79
Answers to questions on Chapter III	104
Answers to questions on Chapter IV	149
Answers to questions on Chapter V	166
Answers to questions on Chapter VI	186
Answers to questions on Chapter VII	228
Answers to questions on Chapter VIII	257
Answers to questions on Chapter IX	275
Answers to questions on Chapter X	303
Answers to questions on Chapter XI	336
Answers to questions on Chapter XII	338
Anti-freezing mixtures.....	181
Arrangement of cylinders	82
Arrangement of cylinders in aviation motors.....	292
Arrangement of cylinders in stationary engines.....	200
Automobile and aeroplane motors, differences in design.	288
Automobile motor operation.....	260
Automobile motor rating (table).....	344
Automobile motor transmission	231
Automobile troubles, operating, remedies for	273
Aviation, fundamental principles of.....	278
Aviation motors, continuity of service.....	294
Aviation motors, cooling system.....	294

	Page
Aviation motors, crank-shaft connections	294
Aviation motors, data on standard types (table)	333
Aviation motor efficiency	301
Aviation motors, fan type	318
Aviation motors, four-cylinder	307
Aviation motors, future possibilities of	334
Aviation motors, Gnome	325
Aviation motors, horizontal opposed type	311
Aviation motors, Liberty	329
Aviation motors, lubricating system	295
Aviation motors, number and arrangement of cylinders	292
Aviation motors, present limitations of	332
Aviation motors, question of weight	290
Aviation motor rating	300
Aviation motor rating (table)	344
Aviation motors, ratio of stroke to diameter	291
Aviation, motor requirements for	278
Aviation motors, rotary types	323
Aviation motors, six-cylinder vertical	309
Aviation motors, speed regulation	296
Aviation motors, star type	320
Aviation motors, Sunbeam	328
Aviation motors, two-cycle	321
Aviation motors, types of	306
Aviation motors, V-type	313
Aviation motors, weights of standard types	332
Aviation motors, X-form	323
Aviation, power requirements for	285

B

Ball and socket connecting link	269
Battery, dry	120
Batteries, storage	124
Bearings	74
Bevel gears	237
Blast-furnace gas	196
Brake, countershaft	270
Brakes, external expansion	270
Brakes, internal expansion	269
Brake lining	271

C

Cam shaft	91
Carbureter, common types of	40

	Page
Carbureter, function of	35
Care of stationary gas motors	226
Calorific values of fuels	7
Care of transmission system	254
Case crank	72
Cells, dry	120
Cells in parallel	122
Cells in series	122
Cells in series, parallel	124
Cells, primary	120
Cells, secondary	124
Cells, storage	124
Chamber mixing	38
Circuit, ignition, for a multiple cylinder engine	138
Circuit, ignition, of a single-cylinder engine	115
Circuit primary	135
Circuit secondary	137
Circulating pumps	174
Circulating systems, water	171
Clutch	251
Coils, heating, for aviation motors	296
Coil, induction	135
Common types of carbureters	40
Commutator	138
Compression leaks	76
Compression leak, remedies for	77
Compression leaks, tests for	77
Condenser	135
Connecting link, ball and socket	269
Connecting rod	71
Constants and formulae	341
Control of gas supply	263
Control of ignition	263
Control of speed of automobiles	264
Continuity of service, in aviation motors	294
Conventional four-cylinder engine for aviation	307
Cooling system	168
Cooling system, air	169
Cooling system for stationary engines	204
Cooling system, in aviation motors	294
Cooling system, motorcycle	170
Cooling troubles	183
Cooling troubles, remedies for	185
Countershaft brake	270
Crank case	72
Crank shaft	72
Crank-shaft connections, in aviation motors	294

	Page
Crank-shaft, offset	73
Cross-head	74
Cups, grease	161
Cups, oil	158
Curtiss aviation motor	318
Cycle, the gas engine	14
Cylinder	64
Cylinders, arrangement of	82
Cylinders, arrangement of—in aviation motors	292
Cylinders, arrangement of—in stationary engines	200
Cylinders, number of—in aviation motors	292
Cylinder oils	154
Cylinder troubles	101
Cylinder troubles, remedies for	101

D

Data on standard aviation motors (table)	333
Diagram, indicator	15
Diesel motor fuel injection system	218
Differential gears	244
Differential gear transmission	247
Differences in design of automobile and aeroplane motors	288
Disadvantages of gravity supply system	32
Distillates and oils	196
Double-acting engine	63
Drift and lift of aeroplanes (table)	284
Dry cells	120
Duplex gas engines	218

E

Effect of advancing and retarding the spark	19
Effect, magnetic, of an electric current	111
Effect of the propeller	298
Effect of varying gas mixtures	18
Effect of varying gas supply	18
Efficiency of aviation motors	301
Efficiency of gas motors	22
Efficiencies, thermal, of stationary gas motors	200
Eight-cylinder engine	99
Electric current, magnetic effect of	111
Electrical measuring instruments	145
Electrical self-starter	262

	Page
Electricity, generation of	108
Electricity, measurement of	109
Electro-magnetic induction, principle of	114
Elementary theory of internal combustion engines	1
Elements of the single cylinder engine	52
Elyria stationary horizontal engines	210
Energy, heat as a form of	1
Engine Cycle	14
Engines, internal-combustion, elementary theory of	1
Engine, multiple cylinder	81
Engine, single-cylinder, elements of	52
Engine, single-cylinder, ignition circuit of	115
Equivalent, mechanical	6
Exhaust valves	67
Explosive mixtures of gas with air	8
External expansion brakes	270

F

Fairbanks-Morse vertical engines	208
Fans	179
Fan-type motors	318
Floating valve	36
Fly-wheel	75
Forced feed non-return oiling system	158
Forced feed oiling system	157
Formulae and constants	341
Four-cycle engine	53
Four-cylinder action (table)	98
Four-cylinder engine for aviation	307
Four-cylinder vertical engine	96
Four-stroke single-acting engine	53
Friction losses in iron piping (table)	184
Fuels, calorific values of	7
Fuels, heat values of	7
Fuel, injection in the Diesel motor	218
Fuels, properties of (table)	10
Fuels, solid and liquid, vaporization of	26
Function of carbureter	35
Fundamental principles of aviation	278
Future possibilities of aviation motors	334

G

Gas and air, explosive mixtures of	8
Gas, blast-furnace	196

	Page
Gas control	263
Gas engine cycle	14
Gas engine fuels, properties of	10
Gas engines, regulation of	20
Gas, illuminating	194
Gas mixtures, effect of varying	18
Gas motors, efficiency of	22
Gas motors, rating of	21
Gas motors, stationary	189
Gas, natural	193
Gasoline, physical properties of	27
Gasoline tests	28
Gas producers	190
Gas supply	25
Gas supply, effect of varying	18
Gas supply troubles	44
Gas supply troubles, remedies of	45
Gauge, pressure	33
Gears, bevel	237
Gearing, mechanism of	233
Gears, planetary	241
General principles of heat radiation	169
General qualities of lubricants	153
Generation of electricity	108
Gears, differential	244
Gears, spur	237
Gears, worm	239
Glossary of technical terms	345
Gnome revolving cylinder motors	325
Governor for stationary engines	201
Graphite	155
Gravity supply system, advantages of	32
Gravity supply system	31
Gravity supply system, disadvantages of	32
Grease	154
Grease cups	161

H

Heating coils for aviation motors	296
Heat as a form of energy	1
Heat radiation, general principles of	169
Heat units	3
Heat value of fuels	7
High-tension magneto	142
Horizontal-opposed type of aviation motor	311

	Page
Horizontal stationary Elyria engines	210
Horizontal two-cylinder engine	93
Horse-power rating of gas motors (table)	344

I

Ignition circuit for a multiple-cylinder engine	138
Ignition circuit of a single-cylinder engine	115
Ignition circuit, primary	135
Ignition circuit, secondary	137
Ignition control	263
Ignition system	106
Ignition spark, requirements of	107
Ignition system, jump-spark	118
Ignition system, make-and-break	115
Ignition troubles	146
Ignition troubles, remedies for	146
Illuminating gas	194
Improper cooling, troubles due to	183
Impulses of power per revolution	81
Indicator diagram	15
Induction coil	135
Induction, electro-magnetic, principle of	114
Injection of fuel in Diesel motors	218
Instruments, electrical measuring	145
Internal combustion engines, elementary theory of	1
Internal expansion brakes	269
International Harvester engine	206

J

Jump-spark ignition system	118
Jackets, water	171

K

Keys	75
------------	----

L

Lay-shaft	204
Leaks, compression	76
Leaks, compression, tests for	77

	Page
Leaks, compression, remedies for	77
Liberty motor	329
Lift and drift of aeroplanes (table)	284
Limitations of aviation motors	332
Limitations of multiple cylinder engines	100
Lining for brakes	271
Losses, frictional, in iron piping (table)	184
Low-tension magneto	142
Lubricants, general qualities of	153
Lubricating system	152
Lubricating troubles	163
Lubricating troubles, remedies for	164
Lubrication of aviation motors	295
Lubricators, multiple	160

M

Magnetic effect of an electric current	111
Magnetic switch	144
Magneto, high-tension	142
Magneto, low-tension	142
Make-and-break ignition system	115
Measurement of electricity	109
Measuring instruments, electrical	145
Mechanical equivalent of heat	6
Mechanism of gearing	233
Mechanism of steering knuckles	266
Mixing chamber	38
Mixtures, explosive of gas with air	8
Mixtures, gas, effect of varying	18
Mixtures, non-freezing	181
Motor-cycle cooling system	170
Motor requirements for aviation	278
Muffler	76
Multiple cylinder engine	81
Multiple cylinder engines, advantages of	100
Multiple cylinder engine, ignition circuit for	138
Multiple cylinder engines, limitations of	100
Multiple lubricators	160

N

Nash engine	210
Natural gas	193
Needle valve	38

	Page
Non-freezing mixtures	181
Non-return forced feed oiling system	158
Nozzle, spraying	38
Number of cylinders in aviation motors	292

O

Offset crank shaft	73
Oil cups	158
Oiling system, forced feed	157
Oiling system, non-return forced-feed	158
Oiling system, sight-feed	155
Oiling system, splash feed	156
Oils and distillates	196
Oils, cylinder	154
Oil strainers	157
Operating troubles of automobile motors	272
Operating troubles of automobiles, remedies for	273
Operation of automobile motors	260

P

Parallel connection of cells	122
Petroleum products, properties of (table)	30
Physical properties of gasoline	27
Pin, wrist	72
Piping	183
Piping friction losses (table)	184
Piston	70
Piston rod	73
Planetary gears	241
Plug, spark	137
Ports	67
Possibilities of aviation motors	334
Power impulses per revolution	81
Power rating of gas motors (table)	344
Power required for propelling aeroplanes (table)	287
Power requirements for aviation	285
Pressure gauge	33
Pressure supply system	33
Pressure and temperature requirements	11
Primary cells	120
Primary ignition circuit	135
Principle of electro-magnetic induction	114

	Page
Principles, fundamental, of aviation	278
Producers, gas	190
Propeller, effect of	298
Properties, physical, of gasoline	27
Properties of gas engine fuels (table)	10
Properties of petroleum products (table)	30
Pumps, circulating	174

Q

Qualities, general, of lubricants	153
Question of weight in aviation motors	290
Questions on Chapter I	23
Questions on Chapter II	47
Questions on Chapter III	78
Questions on Chapter IV	103
Questions on Chapter V	148
Questions on Chapter VI	165
Questions on Chapter VII	185
Questions on Chapter VIII	227
Questions on Chapter IX	256
Questions on Chapter X	274
Questions on Chapter XI	302
Questions on Chapter XII	335

R

Rack and pinion steering system	266
Radiation of heat, general principles of	169
Radiators	178
Range of speeds	249
Rating of automobile motors (table)	344
Rating of aviation motors	300
Rating of gas motors	21
Ratio of stroke to diameter, in aviation motors	291
Rating of aviation motors (table)	344
Rating of stationary engines	197
Regulation of gas engines	20
Remedies for automobile operating troubles	273
Remedies for compression leaks	77
Remedies for cylinder troubles	101
Remedies of gas supply troubles	45
Remedies for cooling troubles	185
Remedies for ignition troubles	146
Remedies for lubricating troubles	164
Requirements for aviation motors	278
Requirements of the ignition spark	107

	Page
Requirements of power for aviation	285
Requirements, temperature and pressure	11
Retarding and advancing the spark, effect of	19
Retarding and advancing the spark	141
Revolving cylinder motors, Gnome	325
Revolving-cylinder motor, valve mechanism	90
Rod, connecting	71
Rod, piston	73
Rotary types of aviation motors	323

S

Saint Mary's tandem engines	215
Scavenging	205
Screw and nut steering system	265
Secondary cells	124
Secondary ignition circuit	137
Self-starter, electrical	262
Series connection of cells	122
Series-parallel connection of cells	124
Shaft, cam	91
Shaft, crank	72
Shaft-lay	204
Single-acting four-stroke engine	53
Single-acting two-stroke engine	57
Single-cylinder engine, elements of	52
Single-cylinder engine, ignition circuit of	115
Sight-feed oiling system	155
Six-cylinder engine	99
Six-cylinder vertical aviation motor	309
Slide-gear transmission	245
Spark, advancing and retarding	141
Spark, effect of advancing and retarding	19
Spark, ignition, requirements of	107
Spark plug	137
Specific gravities of sulphuric acids (table)	129
Speed control	264
Speeds, range of	249
Speed regulation of aviation motors	296
Splash-feed oiling system	156
Spraying nozzle	38
Spur gears	237
Standard aviation motors, data (table)	333
Stationary engines, arrangement of cylinders	200

	Page
Stationary engines, cooling system	204
Stationary engines, efficiencies of	200
Stationary engines, governor	201
Stationary engines, rating of	197
Stationary gas motors	189
Stationary gas motors, care of	226
Stationary gas motors, used for submarines	225
Starting the engine	261
Starting devices, electrical	262
Star-type motors	320
Steering knuckles, mechanism of	266
Steering system	264
Steering system, screw and nut	265
Steering system, rack and pinion	266
Strainers, oil	157
Stroke to diameter, ratio of, in aviation motors	291
Storage batteries	124
Submarines driven by gas motor	225
Sunbeam aviation motor	328
Sulphuric acids, specific gravities of (table)	129
Supply of air	39
Supply of gas	25
Supply system, gravity	31
Supply system, gravity, advantages of	32
Supply system, gravity, disadvantages of	32
Supply system, pressure	33
Supply, troubles of gas	44
Switch, magnetic	144

T

Tandem engines, Saint Mary's	215
Technical terms, glossary of	345
Tests for compression leaks	77
Tests of gasoline	28
Temperature and pressure requirements	11
Theory (elementary) of internal combustion engines ..	1
Thermal efficiencies of stationary gas motors	200
Transmission system of automobile motors	231
Throttle valve	40
Transmission, differential gear	247
Transmission, slide-gear	245
Transmission system, care of	254
Troubles, cooling	183
Troubles, cooling, remedies for	185
Troubles, cylinder	101

	Page
Troubles, cylinder, remedies for	101
Troubles due to improper cooling	183
Troubles, gas supply	44
Troubles, ignition	146
Troubles, ignition, remedies for	146
Troubles, lubricating	163
Troubles, lubricating, remedies for	164
Troubles, operation, of automobile motors	272
Two-cycle aviation motors	321
Two-cycle engine	57
Two-cylinder horizontal engine	93
Two-cylinder vertical engine	94
Two-stroke single-acting engine	57
Types of aviation motors	306
Types of carbureter	40

U

Units, heat	3
Useful constants and formulae	341
Use of stationary gas motors for submarines	225

V

Vaporization of solid and liquid fuels	26
Valves, admission and exhaust	67
Valve, floating	36
Valve, needle	38
Valve mechanism of revolving-cylinder motor	90
Valve, throttle	40
V-type motors	313
Valves of lift and drift of aeroplanes (table)	284
Varying gas mixtures, effect of	18
Varying gas supply, effect of	18
Vertical engines, Fairbanks-Morse	208
Vertical four-cylinder engine	96
Vertical six-cylinder aviation motor	309
Vertical two-cylinder engine	94

W

Water circulating systems	171
Water jackets	171
Weights of aeroplane motors	332

